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# 14

## Sag and Tension of Conductor

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The energized conductors of transmission and distribution lines must be placed to totally eliminate the possibility of injury to people. Overhead conductors, however, elongate with time, temperature, and tension, thereby changing their original positions after installation. Despite the effects of weather and loading on a line, the conductors must remain at safe distances from buildings, objects, and people or vehicles passing beneath the line at all times. To ensure this safety, the shape of the terrain along the right-of-way, the height and lateral position of the conductor support points, and the position of the conductor between support points under all wind, ice, and temperature conditions must be known.

Bare overhead transmission or distribution conductors are typically quite flexible and uniform in weight along their length. Because of these characteristics, they take the form of a catenary (Ehrenberg, 1935; Winkelmann, 1959) between support points. The shape of the catenary changes with conductor temperature, ice and wind loading, and time. To ensure adequate vertical and horizontal clearance under all weather and electrical loadings, and to ensure that the breaking strength of the conductor is not exceeded, the behavior of the conductor catenary under all conditions must be known before the line is designed. The future behavior of the conductor is determined through calculations commonly referred to as sag-tension calculations.

Sag-tension calculations predict the behavior of conductors based on recommended tension limits under varying loading conditions. These tension limits specify certain percentages of the conductor's

rated breaking strength that are not to be exceeded upon installation or during the life of the line. These conditions, along with the elastic and permanent elongation properties of the conductor, provide the basis for determining the amount of resulting sag during installation and long-term operation of the line.

Accurately determined initial sag limits are essential in the line design process. Final sags and tensions depend on initial installed sags and tensions and on proper handling during installation. The final sag shape of conductors is used to select support point heights and span lengths so that the minimum clearances will be maintained over the life of the line. If the conductor is damaged or the initial sags are incorrect, the line clearances may be violated or the conductor may break during heavy ice or wind loadings.

## 14.1 Catenary Cables

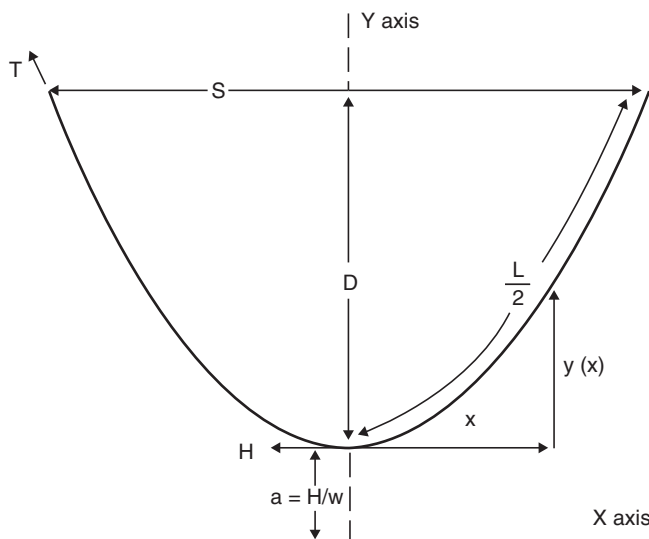
A bare-stranded overhead conductor is normally held clear of objects, people, and other conductors by periodic attachment to insulators. The elevation differences between the supporting structures affect the shape of the conductor catenary. The catenary's shape has a distinct effect on the sag and tension of the conductor, and therefore, must be determined using well-defined mathematical equations.

### 14.1.1 Level Spans

The shape of a catenary is a function of the conductor weight per unit length,  $w$ , the horizontal component of tension,  $H$ , span length,  $S$ , and the maximum sag of the conductor,  $D$ . Conductor sag and span length are illustrated in Fig. 14.1 for a level span.

The exact catenary equation uses hyperbolic functions. Relative to the low point of the catenary curve shown in Fig. 14.1, the height of the conductor,  $y(x)$ , above this low point is given by the following equation:

$$y(x) = \frac{H}{w} \cosh\left(\left(\frac{w}{H}x\right) - 1\right) = \frac{w(x^2)}{2H} \quad (14.1)$$



**FIGURE 14.1** The catenary curve for level spans.

Note that  $x$  is positive in either direction from the low point of the catenary. The expression to the right is an approximate parabolic equation based upon a MacLaurin expansion of the hyperbolic cosine.

For a level span, the low point is in the center, and the sag,  $D$ , is found by substituting  $x = S/2$  in the preceding equations. The exact and approximate parabolic equations for sag become the following:

$$D = \frac{H}{w} \left( \cosh \left( \frac{wS}{2H} \right) - 1 \right) = \frac{w(S^2)}{8H} \quad (14.2)$$

The ratio,  $H/w$ , which appears in all of the preceding equations, is commonly referred to as the catenary constant. An increase in the catenary constant, having the units of length, causes the catenary curve to become shallower and the sag to decrease. Although it varies with conductor temperature, ice and wind loading, and time, the catenary constant typically has a value in the range of several thousand feet for most transmission-line catenaries.

The approximate or parabolic expression is sufficiently accurate as long as the sag is less than 5% of the span length. As an example, consider a 1000-ft span of Drake conductor ( $w = 1.096$  lb/ft) installed at a tension of 4500 lb. The catenary constant equals 4106 ft. The calculated sag is 30.48 ft and 30.44 ft using the hyperbolic and approximate equations, respectively. Both estimates indicate a sag-to-span ratio of 3.4% and a sag difference of only 0.5 in.

The horizontal component of tension,  $H$ , is equal to the conductor tension at the point in the catenary where the conductor slope is horizontal. For a level span, this is the midpoint of the span length. At the ends of the level span, the conductor tension,  $T$ , is equal to the horizontal component plus the conductor weight per unit length,  $w$ , multiplied by the sag,  $D$ , as shown in the following:

$$T = H + wD \quad (14.3)$$

Given the conditions in the preceding example calculation for a 1000-ft level span of Drake ACSR, the tension at the attachment points exceeds the horizontal component of tension by 33 lb. It is common to perform sag-tension calculations using the horizontal tension component, but the average of the horizontal and support point tension is usually listed in the output.

### 14.1.2 Conductor Length

Application of calculus to the catenary equation allows the calculation of the conductor length,  $L(x)$ , measured along the conductor from the low point of the catenary in either direction.

The resulting equation becomes:

$$L(x) = \frac{H}{w} \sinh \left( \frac{wx}{H} \right) = x \left( 1 + \frac{x^2(w^2)}{6H^2} \right) \quad (14.4)$$

For a level span, the conductor length corresponding to  $x = S/2$  is half of the total conductor length and the total length,  $L$ , is:

$$L = \left( \frac{2H}{w} \right) \sinh \left( \frac{Sw}{2H} \right) = S \left( 1 + \frac{S^2(w^2)}{24H^2} \right) \quad (14.5)$$

The parabolic equation for conductor length can also be expressed as a function of sag,  $D$ , by substitution of the sag parabolic equation, giving:

$$L = S + \frac{8D^2}{3S} \quad (14.6)$$

### 14.1.3 Conductor Slack

The difference between the conductor length,  $L$ , and the span length,  $S$ , is called slack. The parabolic equations for slack may be found by combining the preceding parabolic equations for conductor length,  $L$ , and sag,  $D$ :

$$L - S = S^3 \left( \frac{w^2}{24H^2} \right) = D^2 \left( \frac{8}{3S} \right) \quad (14.7)$$

While slack has units of length, it is often expressed as the percentage of slack relative to the span length. Note that slack is related to the cube of span length for a given  $H/w$  ratio and to the square of sag for a given span. For a series of spans having the same  $H/w$  ratio, the total slack is largely determined by the longest spans. It is for this reason that the ruling span is nearly equal to the longest span rather than the average span in a series of suspension spans.

Equation (14.7) can be inverted to obtain a more interesting relationship showing the dependence of sag,  $D$ , upon slack,  $L-S$ :

$$D = \sqrt{\frac{3S(L-S)}{8}} \quad (14.8)$$

As can be seen from the preceding equation, small changes in slack typically yield large changes in conductor sag.

### 14.1.4 Inclined Spans

Inclined spans may be analyzed using essentially the same equations that were used for level spans. The catenary equation for the conductor height above the low point in the span is the same. However, the span is considered to consist of two separate sections, one to the right of the low point and the other to the left as shown in Fig. 14.2 (Winkermann, 1959). The shape of the catenary relative to the low point is unaffected by the difference in suspension point elevation (span inclination).

In each direction from the low point, the conductor elevation,  $y(x)$ , relative to the low point is given by:

$$y(x) = \frac{H}{w} \cosh \left( \left( \frac{w}{H} x \right) - 1 \right) = \frac{w(x^2)}{2H} \quad (14.9)$$

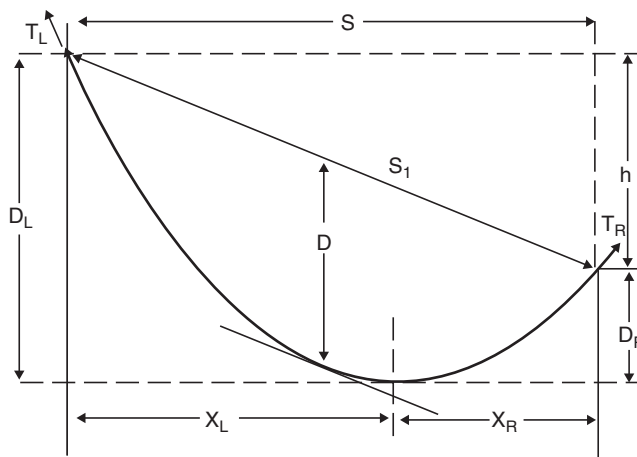


FIGURE 14.2 Inclined catenary span.

Note that  $x$  is considered positive in either direction from the low point.

The horizontal distance,  $x_L$ , from the left support point to the low point in the catenary is:

$$x_L = \frac{S}{2} \left( 1 + \frac{h}{4D} \right) \quad (14.10)$$

The horizontal distance,  $x_R$ , from the right support point to the low point of the catenary is:

$$x_R = \frac{S}{2} \left( 1 - \frac{h}{4D} \right) \quad (14.11)$$

where  $S$  = horizontal distance between support points.

$h$  = vertical distance between support points.

$S_l$  = straight-line distance between support points.

$D$  = sag measured vertically from a line through the points of conductor support to a line tangent to the conductor.

The midpoint sag,  $D$ , is approximately equal to the sag in a horizontal span equal in length to the inclined span,  $S_l$ .

Knowing the horizontal distance from the low point to the support point in each direction, the preceding equations for  $y(x)$ ,  $L$ ,  $D$ , and  $T$  can be applied to each side of the inclined span.

The total conductor length,  $L$ , in the inclined span is equal to the sum of the lengths in the  $x_R$  and  $x_L$  sub-span sections:

$$L = S + (x_R^3 + x_L^3) \left( \frac{w^2}{6H^2} \right) \quad (14.12)$$

In each sub-span, the sag is relative to the corresponding support point elevation:

$$D_R = \frac{wx_R^2}{2H} \quad D_L = \frac{wx_L^2}{2H} \quad (14.13)$$

or in terms of sag,  $D$ , and the vertical distance between support points:

$$D_R = D \left( 1 - \frac{h}{4D} \right)^2 \quad D_L = D \left( 1 + \frac{h}{4D} \right)^2 \quad (14.14)$$

and the maximum tension is:

$$T_R = H + wD_R \quad T_L = H + wD_L \quad (14.15)$$

or in terms of upper and lower support points:

$$T_u = T_l + wh \quad (14.16)$$

where  $D_R$  = sag in right sub-span section

$D_L$  = sag in left sub-span section

$T_R$  = tension in right sub-span section

$T_L$  = tension in left sub-span section

$T_u$  = tension in conductor at upper support

$T_l$  = tension in conductor at lower support

The horizontal conductor tension is equal at both supports. The vertical component of conductor tension is greater at the upper support and the resultant tension,  $T_{tr}$  is also greater.

### 14.1.5 Ice and Wind Conductor Loads

When a conductor is covered with ice and/or is exposed to wind, the effective conductor weight per unit length increases. During occasions of heavy ice and/or wind load, the conductor catenary tension increases dramatically along with the loads on angle and deadend structures. Both the conductor and its supports can fail unless these high-tension conditions are considered in the line design.

The National Electric Safety Code (NESC) suggests certain combinations of ice and wind corresponding to heavy, medium, and light loading regions of the United States. Figure 14.3 is a map of the U.S. indicating those areas (NESC, 1993). The combinations of ice and wind corresponding to loading region are listed in Table 14.1.

The NESC also suggests that increased conductor loads due to high wind loads without ice be considered. Figure 14.4 shows the suggested wind pressure as a function of geographical area for the United States (ASCE Std 7–88).

Certain utilities in very heavy ice areas use glaze ice thicknesses of as much as two inches to calculate iced conductor weight. Similarly, utilities in regions where hurricane winds occur may use wind loads as high as 34 lb/ft<sup>2</sup>.

As the NESC indicates, the degree of ice and wind loads varies with the region. Some areas may have heavy icing, whereas some areas may have extremely high winds. The loads must be accounted for in the line design process so they do not have a detrimental effect on the line. Some of the effects of both the individual and combined components of ice and wind loads are discussed in the following.

#### 14.1.5.1 Ice Loading

The formation of ice on overhead conductors may take several physical forms (glaze ice, rime ice, or wet snow). The impact of lower density ice formation is usually considered in the design of line sections at high altitudes.

The formation of ice on overhead conductors has the following influence on line design:

- Ice loads determine the maximum vertical conductor loads that structures and foundations must withstand.
- In combination with simultaneous wind loads, ice loads also determine the maximum transverse loads on structures.

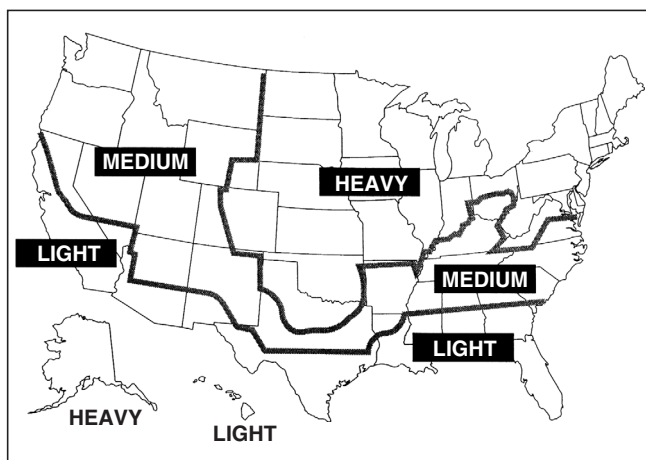


FIGURE 14.3 Ice and wind load areas of the U.S.

TABLE 14.1 Definitions of Ice and Wind Load for NESC Loading Areas

|                                                          | Loading Districts |        |       |                      |
|----------------------------------------------------------|-------------------|--------|-------|----------------------|
|                                                          | Heavy             | Medium | Light | Extreme Wind Loading |
| Radial thickness of ice                                  |                   |        |       |                      |
| (in.)                                                    | 0.50              | 0.25   | 0     | 0                    |
| (mm)                                                     | 12.5              | 6.5    | 0     | 0                    |
| Horizontal wind pressure                                 |                   |        |       |                      |
| (lb/ft <sup>2</sup> )                                    | 4                 | 4      | 9     | See Fig. 14.4        |
| (Pa)                                                     | 190               | 190    | 430   |                      |
| Temperature                                              |                   |        |       |                      |
| (°F)                                                     | 0                 | +15    | +30   | +60                  |
| (°C)                                                     | −20               | −10    | −1    | +15                  |
| Constant to be added to the resultant for all conductors |                   |        |       |                      |
| (lb/ft)                                                  | 0.30              | 0.20   | 0.05  | 0.0                  |
| (N/m)                                                    | 4.40              | 2.50   | 0.70  | 0.0                  |

- In regions of heavy ice loads, the maximum sags and the permanent increase in sag with time (difference between initial and final sags) may be due to ice loadings.

Ice loads for use in designing lines are normally derived on the basis of past experience, code requirements, state regulations, and analysis of historical weather data. Mean recurrence intervals for heavy ice loadings are a function of local conditions along various routings. The impact of varying assumptions concerning ice loading can be investigated with line design software.

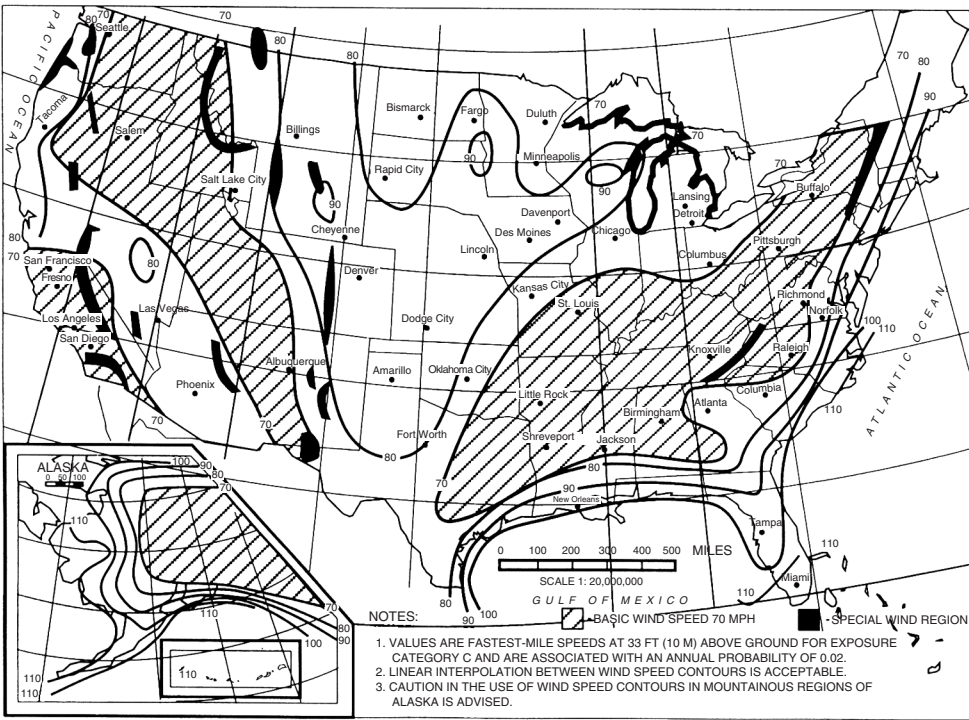


FIGURE 14.4 Wind pressure design values in the United States. Maximum recorded wind speed in miles/hour. (From Overend, P.R. and Smith, S., *Impulse Time Method of Sag Measurement*, American Society of Civil Engineers. With permission.)



**TABLE 14.2** Ratio of Iced to Bare Conductor Weight

| ACSR Conductor            | $D_c$ , in. | $W_{bare}$ , lb/ft | $W_{ice}$ , lb/ft | $W_{bare} + W_{ice}$ |
|---------------------------|-------------|--------------------|-------------------|----------------------|
|                           |             |                    |                   | $W_{bare}$           |
| #1/0 AWG -6/1 "Raven"     | 0.398       | 0.1451             | 0.559             | 4.8                  |
| 477 kcmil-26/7 "Hawk"     | 0.858       | 0.6553             | 0.845             | 2.3                  |
| 1590 kcmil-54/19 "Falcon" | 1.545       | 2.042              | 1.272             | 1.6                  |

The calculation of ice loads on conductors is normally done with an assumed glaze ice density of 57 lb/ft<sup>3</sup>. The weight of ice per unit length is calculated with the following equation:

$$w_{ice} = 1.244t(D_c + t) \quad (14.17)$$

where  $t$  = thickness of ice, in.

$D_c$  = conductor outside diameter, in.

$w_{ice}$  = resultant weight of ice, lb/ft

The ratio of iced weight to bare weight depends strongly upon conductor diameter. As shown in Table 14.2 for three different conductors covered with 0.5-in radial glaze ice, this ratio ranges from 4.8 for #1/0 AWG to 1.6 for 1590-kcmil conductors. As a result, small diameter conductors may need to have a higher elastic modulus and higher tensile strength than large conductors in heavy ice and wind loading areas to limit sag.

#### 14.1.5.2 Wind Loading

Wind loadings on overhead conductors influence line design in a number of ways:

- The maximum span between structures may be determined by the need for horizontal clearance to edge of right-of-way during moderate winds.
- The maximum transverse loads for tangent and small angle suspension structures are often determined by infrequent high wind-speed loadings.
- Permanent increases in conductor sag may be determined by wind loading in areas of light ice load.

Wind pressure load on conductors,  $P_w$ , is commonly specified in lb/ft<sup>2</sup>. The relationship between  $P_w$  and wind velocity is given by the following equation:

$$P_w = 0.0025(V_w)^2 \quad (14.18)$$

where  $V_w$  = the wind speed in miles per hour.

The wind load per unit length of conductor is equal to the wind pressure load,  $P_w$ , multiplied by the conductor diameter (including radial ice of thickness  $t$ , if any), is given by the following equation:

$$W_w = P_w \frac{(D_c + 2t)}{12} \quad (14.19)$$

#### 14.1.5.3 Combined Ice and Wind Loading

If the conductor weight is to include both ice and wind loading, the resultant magnitude of the loads must be determined vectorially. The weight of a conductor under both ice and wind loading is given by the following equation:

$$w_{w+i} = \sqrt{(w_b + w_i)^2 + (W_w)^2} \quad (14.20)$$

where  $w_b$  = bare conductor weight per unit length, lb/ft  
 $w_i$  = weight of ice per unit length, lb/ft  
 $w_w$  = wind load per unit length, lb/ft  
 $w_{w \pm i}$  = resultant of ice and wind loads, lb/ft

The NESC prescribes a safety factor,  $K$ , in pounds per foot, dependent upon loading district, to be added to the resultant ice and wind loading when performing sag and tension calculations. Therefore, the total resultant conductor weight,  $w$ , is:

$$w = w_{w+i} + K \quad (14.21)$$

### 14.1.6 Conductor Tension Limits

The NESC recommends limits on the tension of bare overhead conductors as a percentage of the conductor's rated breaking strength. The tension limits are: 60% under maximum ice and wind load, 33.3% initial unloaded (when installed) at 60°F, and 25% final unloaded (after maximum loading has occurred) at 60°F. It is common, however, for lower unloaded tension limits to be used. Except in areas experiencing severe ice loading, it is not unusual to find tension limits of 60% maximum, 25% unloaded initial, and 15% unloaded final. This set of specifications could easily result in an actual maximum tension on the order of only 35 to 40%, an initial tension of 20% and a final unloaded tension level of 15%. In this case, the 15% tension limit is said to govern.

Transmission-line conductors are normally not covered with ice, and winds on the conductor are usually much lower than those used in maximum load calculations. Under such everyday conditions, tension limits are specified to limit aeolian vibration to safe levels. Even with everyday lower tension levels of 15 to 20%, it is assumed that vibration control devices will be used in those sections of the line that are subject to severe vibration. Aeolian vibration levels, and thus appropriate unloaded tension limits, vary with the type of conductor, the terrain, span length, and the use of dampers. Special conductors, such as ACSS, SDC, and VR, exhibit high self-damping properties and may be installed to the full code limits, if desired.

## 14.2 Approximate Sag-Tension Calculations

Sag-tension calculations, using exacting equations, are usually performed with the aid of a computer; however, with certain simplifications, these calculations can be made with a handheld calculator. The latter approach allows greater insight into the calculation of sags and tensions than is possible with complex computer programs. Equations suitable for such calculations, as presented in the preceding section, can be applied to the following example:

It is desired to calculate the sag and slack for a 600-ft level span of 795 kcmil-26/7 ACSR "Drake" conductor. The bare conductor weight per unit length,  $w_b$ , is 1.094 lb/ft. The conductor is installed with a horizontal tension component,  $H$ , of 6300 lb, equal to 20% of its rated breaking strength of 31,500 lb.

By use of Eq. (14.2), the sag for this level span is:

$$D = \frac{1.094(600^2)}{(8)6300} = 7.81 \text{ ft (2.38 m)}$$

The length of the conductor between the support points is determined using Eq. (14.6):

$$L = 600 + \frac{8(7.81)^2}{3(600)} = 600.27 \text{ ft (182.96 m)}$$

Note that the conductor length depends solely on span and sag. It is not directly dependent on conductor tension, weight, or temperature. The conductor slack is the conductor length minus the span length; in this example, it is 0.27 ft (0.0826 m).

### 14.2.1 Sag Change with Thermal Elongation

ACSR and AAC conductors elongate with increasing conductor temperature. The rate of linear thermal expansion for the composite ACSR conductor is less than that of the AAC conductor because the steel strands in the ACSR elongate at approximately half the rate of aluminum. The effective linear thermal expansion coefficient of a non-homogenous conductor, such as Drake ACSR, may be found from the following equations (Fink and Beatty):

$$E_{AS} = E_{AL} \left( \frac{A_{AL}}{A_{TOTAL}} \right) + E_{ST} \left( \frac{A_{ST}}{A_{TOTAL}} \right) \quad (14.22)$$

$$\alpha_{AS} = \alpha_{AL} \left( \frac{E_{AL}}{E_{AS}} \right) \left( \frac{A_{AL}}{A_{TOTAL}} \right) + \alpha_{ST} \left( \frac{E_{ST}}{E_{AS}} \right) \left( \frac{A_{ST}}{A_{TOTAL}} \right) \quad (14.23)$$

where  $E_{AL}$  = Elastic modulus of aluminum, psi  
 $E_{ST}$  = Elastic modulus of steel, psi  
 $E_{AS}$  = Elastic modulus of aluminum-steel composite, psi  
 $A_{AL}$  = Area of aluminum strands, square units  
 $A_{ST}$  = Area of steel strands, square units  
 $A_{TOTAL}$  = Total cross-sectional area, square units  
 $\alpha_{AL}$  = Aluminum coefficient of linear thermal expansion, per °F  
 $\alpha_{ST}$  = Steel coefficient of thermal elongation, per °F  
 $\alpha_{AS}$  = Composite aluminum-steel coefficient of thermal elongation, per °F

The elastic moduli for solid aluminum wire is 10 million psi and for steel wire is 30 million psi. The elastic moduli for stranded wire is reduced. The modulus for stranded aluminum is assumed to be 8.6 million psi for all strandings. The moduli for the steel core of ACSR conductors varies with stranding as follows:

- $27.5 \times 10^6$  for single-strand core
- $27.0 \times 10^6$  for 7-strand core
- $26.5 \times 10^6$  for 19-strand core

Using elastic moduli of 8.6 and 27.0 million psi for aluminum and steel, respectively, the elastic modulus for Drake ACSR is:

$$E_{AS} = (8.6 \times 10^6) \left( \frac{0.6247}{0.7264} \right) + (27.0 \times 10^6) \left( \frac{0.1017}{0.7264} \right) = 11.2 \times 10^6 \text{ psi}$$

and the coefficient of linear thermal expansion is:

$$\begin{aligned} \alpha_{AS} &= 12.8 \times 10^{-6} \left( \frac{8.6 \times 10^6}{11.2 \times 10^6} \right) \left( \frac{0.6247}{0.7264} \right) + 6.4 \times 10^{-6} \left( \frac{27.0 \times 10^6}{11.2 \times 10^6} \right) \left( \frac{0.1017}{0.7264} \right) \\ &= 10.6 \times 10^{-6} / ^\circ\text{F} \end{aligned}$$

If the conductor temperature changes from a reference temperature,  $T_{REF}$ , to another temperature,  $T$ , the conductor length,  $L$ , changes in proportion to the product of the conductor's effective thermal elongation coefficient,  $\alpha_{AS}$ , and the change in temperature,  $T - T_{REF}$ , as shown below:

$$L_T = L_{T_{REF}} (1 + \alpha_{AS} (T - T_{REF})) \quad (14.24)$$

For example, if the temperature of the Drake conductor in the preceding example increases from 60°F (15°C) to 167°F (75°C), then the length at 60°F increases by 0.68 ft (0.21 m) from 600.27 ft (182.96 m) to 600.95 ft (183.17 m):

$$L_{(167^{\circ}F)} = 600.27(1 + (10.6 \times 10^{-6})(167 - 60)) = 600.95 \text{ ft}$$

Ignoring for the moment any change in length due to change in tension, the sag at 167°F (75°C) may be calculated for the conductor length of 600.95 ft (183.17 m) using Eq. (14.8):

$$D = \sqrt{\frac{3(600)(0.95)}{8}} = 14.62 \text{ ft}$$

Using a rearrangement of Eq. (14.2), this increased sag is found to correspond to a decreased tension of:

$$H = \frac{w(S^2)}{8D} = \frac{1.094(600^2)}{8(14.62)} = 3367 \text{ lb}$$

If the conductor were inextensible, that is, if it had an infinite modulus of elasticity, then these values of sag and tension for a conductor temperature of 167°F would be correct. For any real conductor, however, the elastic modulus of the conductor is finite and changes in tension do change the conductor length. Use of the preceding calculation, therefore, will overstate the increase in sag.

## 14.2.2 Sag Change Due to Combined Thermal and Elastic Effects

With moduli of elasticity around the 8.6 million psi level, typical bare aluminum and ACSR conductors elongate about 0.01% for every 1000 psi change in tension. In the preceding example, the increase in temperature caused an increase in length and sag and a decrease in tension, but the effect of tension change on length was ignored.

As discussed later, concentric-lay stranded conductors, particularly non-homogenous conductors such as ACSR, are not inextensible. Rather, they exhibit quite complex elastic and plastic behavior. Initial loading of conductors results in elongation behavior substantially different from that caused by loading many years later. Also, high tension levels caused by heavy ice and wind loads cause a permanent increase in conductor length, affecting subsequent elongation under various conditions.

Accounting for such complex stress-strain behavior usually requires a sophisticated, computer-aided approach. For illustration purposes, however, the effect of permanent elongation of the conductor on sag and tension calculations will be ignored and a simplified elastic conductor assumed. This idealized conductor is assumed to elongate linearly with load and to undergo no permanent increase in length regardless of loading or temperature. For such a conductor, the relationship between tension and length is as follows:

$$L_H = L_{H_{REF}} \left( 1 + \frac{H - H_{REF}}{E_C A} \right) \quad (14.25)$$

where  $L_H$  = Length of conductor under horizontal tension  $H$

$L_{H_{REF}}$  = Length of conductor under horizontal reference tension  $H_{REF}$

$E_C$  = Elastic modulus of elasticity of the conductor, psi

$A$  = Cross-sectional area, in.<sup>2</sup>

In calculating sag and tension for extensible conductors, it is useful to add a step to the preceding calculation of sag and tension for elevated temperature. This added step allows a separation of thermal elongation and elastic elongation effects, and involves the calculation of a zero tension length, ZTL, at the conductor temperature of interest,  $T_{cdr}$ .

This  $ZTL(T_{cdr})$  is the conductor length attained if the conductor is taken down from its supports and laid on the ground with no tension. By reducing the initial tension in the conductor to zero, the elastic elongation is also reduced to zero, shortening the conductor. It is possible, then, for the zero tension length to be less than the span length.

Consider the preceding example for Drake ACSR in a 600-ft level span. The initial conductor temperature is 60°F, the conductor length is 600.27 ft, and  $E_{AS}$  is calculated to be 11.2 million psi. Using Eq. (14.25), the reduction of the initial tension from 6300 lb to zero yields a ZTL (60°F) of:

$$ZTL_{(60^\circ F)} = 600.27 \left( 1 + \frac{0 - 6300}{(11.2 \times 10^6)0.7264} \right) = 599.81 \text{ ft}$$

Keeping the tension at zero and increasing the conductor temperature to 167°F yields a purely thermal elongation. The zero tension length at 167°F can be calculated using Eq. (14.24):

$$ZTL_{(167^\circ F)} = 599.81 \left( 1 + \left( 10.6 \times 10^{-6} \right) (167 - 60) \right) = 600.49 \text{ ft}$$

According to Eqs. (14.2) and (14.8), this length corresponds to a sag of 10.5 ft and a horizontal tension of 4689 lb. However, this length was calculated for zero tension and will elongate elastically under tension. The actual conductor sag-tension determination requires a process of iteration as follows:

1. As described above, the conductor's zero tension length, calculated at 167°F (75°C), is 600.49 ft, sag is 10.5 ft, and the horizontal tension is 4689 lb.
2. Because the conductor is elastic, application of Eq. (14.25) shows the tension of 4689 lb will increase the conductor length from 600.49 ft to:

$$L_{l(167^\circ F)} = 600.49 \left( 1 + \frac{4689 - 0}{0.7264(11.2 \times 10^6)} \right) = 600.84 \text{ ft}$$

3. The sag,  $D_{l(167^\circ F)}$ , corresponding to this length is calculated using Eq. (14.8):

$$D_{l(167^\circ F)} = \sqrt{\frac{3(600)(0.84)}{8}} = 13.72 \text{ ft}$$

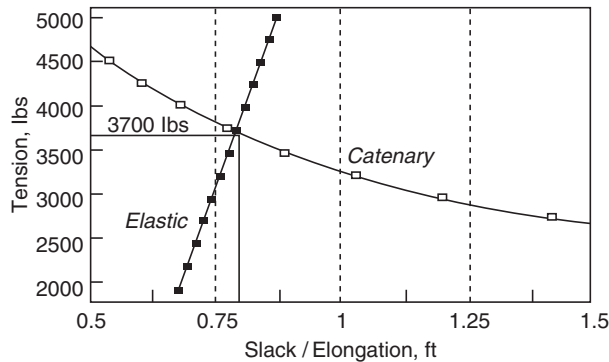
4. Using Eq. (14.2), this sag yields a new horizontal tension,  $H_{l(167^\circ F)}$ , of:

$$H_1 = \frac{1.094(600^2)}{8(13.7)} = 3588 \text{ lb}$$

A new trial tension is taken as the average of  $H$  and  $H_1$ , and the process is repeated. The results are described in Table 14.3.

**TABLE 14.3** Iterative Solution for Increased Conductor Temperature

| Iteration # | Length, $L_n$ , ft | Sag, $D_n$ , ft | Tension, $H_n$ , lb | New Trial Tension, lb          |
|-------------|--------------------|-----------------|---------------------|--------------------------------|
| ZTL         | 600.550            | 11.1            | 4435                | —                              |
| 1           | 600.836            | 13.7            | 3593                | $\frac{4435 + 3593}{2} = 4014$ |
| 2           | 600.809            | 13.5            | 3647                | $\frac{3647 + 4014}{2} = 3831$ |
| 3           | 600.797            | 13.4            | 3674                | $\frac{3674 + 3831}{2} = 3753$ |
| 4           | 600.792            | 13.3            | 3702                | $\frac{3702 + 3753}{2} = 3727$ |



**FIGURE 14.5** Sag-tension solution for 600-ft span of Drake at 167°F.

Note that the balance of thermal and elastic elongation of the conductor yields an equilibrium tension of approximately 3700 lbs and a sag of 13.3 ft. The calculations of the previous section, which ignored elastic effects, results in lower tension, 3440 lb, and a greater sag, 14.7 ft.

Slack is equal to the excess of conductor length over span length. The preceding table can be replaced by a plot of the catenary and elastic curves on a graph of slack vs tension. The solution occurs at the intersection of the two curves. Figure 14.5 shows the tension versus slack curves intersecting at a tension of 3700 lb, which agrees with the preceding calculations.

### 14.2.3 Sag Change Due to Ice Loading

As a final example of sag-tension calculation, calculate the sag and tension for the 600-ft Drake span with the addition of 0.5 inches of radial ice and a drop in conductor temperature to 0°F. Employing Eq. (14.17), the weight of the conductor increases by:

$$w_{ice} = 1.244t(D + t)$$

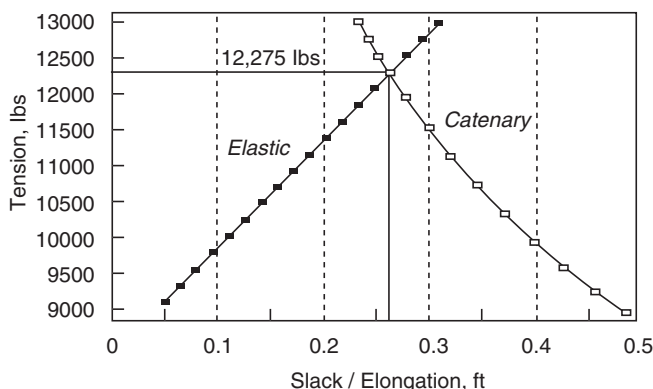
$$w_{ice} = 1.244(0.5)(1.108 + 0.5) = 1.000 \text{ lb/ft}$$

As in the previous example, the calculation uses the conductor's zero tension length at 60°F, which is the same as that found in the previous section, 599.81 ft. The ice loading is specified for a conductor temperature of 0°F, so the ZTL(0°F), using Eq. (14.24), is:

$$ZTL_{(0^\circ F)} = 599.81[1 + (10.6 \times 10^{-6})(0 - 60)] = 599.43 \text{ ft}$$

As in the case of sag-tension at elevated temperatures, the conductor tension is a function of slack and elastic elongation. The conductor tension and the conductor length are found at the point of intersection of the catenary and elastic curves (Fig. 14.6). The intersection of the curves occurs at a horizontal tension component of 12,275 lb, not very far from the crude initial estimate of 12,050 lb that ignored elastic effects. The sag corresponding to this tension and the iced conductor weight per unit length is 9.2 ft.

In spite of doubling the conductor weight per unit length by adding 0.5 in. of ice, the sag of the conductor is much less than the sag at 167°F. This condition is generally true for transmission conductors where minimum ground clearance is determined by the high temperature rather than the heavy loading condition. Small distribution conductors, such as the 1/0 AWG ACSR in Table 14.1, experience a much larger ice-to-conductor weight ratio (4.8), and the conductor sag under maximum wind and ice load may exceed the sag at moderately higher temperatures.



**FIGURE 14.6** Sag-tension solution for 600-ft span of Drake at 0°F and 0.5 in. ice.

The preceding approximate tension calculations could have been more accurate with the use of actual stress-strain curves and graphic sag-tension solutions, as described in detail in *Graphic Method for Sag Tension Calculations for ACSR and Other Conductors* (Aluminum Company of America, 1961). This method, although accurate, is very slow and has been replaced completely by computational methods.

## 14.3 Numerical Sag-Tension Calculations

Sag-tension calculations are normally done numerically and allow the user to enter many different loading and conductor temperature conditions. Both initial and final conditions are calculated and multiple tension constraints can be specified. The complex stress-strain behavior of ACSR-type conductors can be modeled numerically, including both temperature, and elastic and plastic effects.

### 14.3.1 Stress-Strain Curves

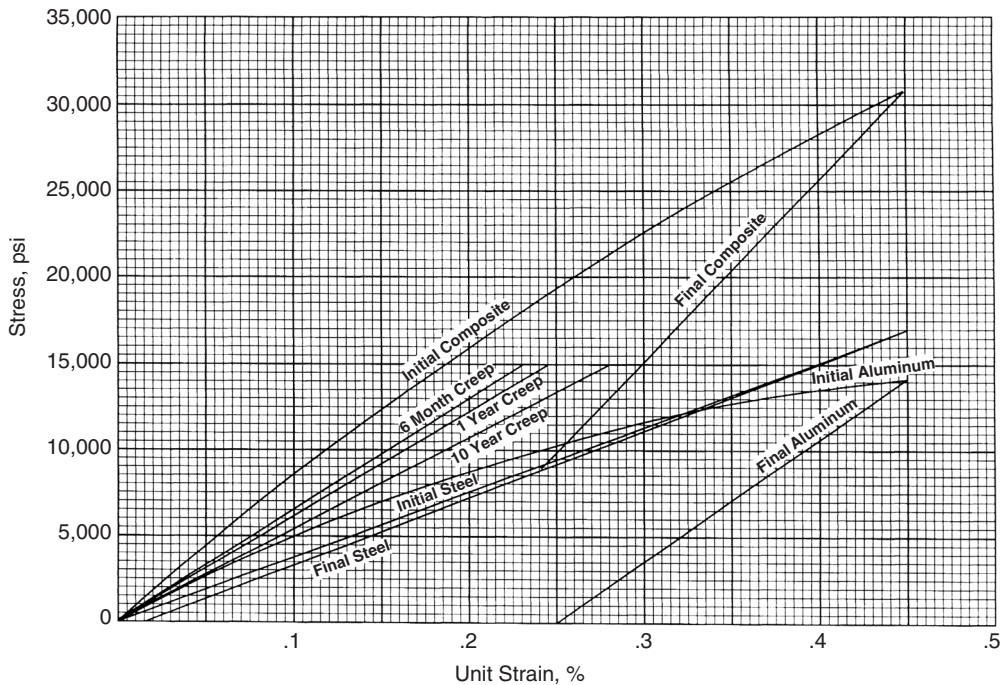
Stress-strain curves for bare overhead conductor include a minimum of an initial curve and a final curve over a range of elongations from 0 to 0.45%. For conductors consisting of two materials, an initial and final curve for each is included. Creep curves for various lengths of time are typically included as well.

Overhead conductors are not purely elastic. They stretch with tension, but when the tension is reduced to zero, they do not return to their initial length. That is, conductors are plastic; the change in conductor length cannot be expressed with a simple linear equation, as for the preceding hand calculations. The permanent length increase that occurs in overhead conductors yields the difference in initial and final sag-tension data found in most computer programs.

Figure 14.7 shows a typical stress-strain curve for a 26/7 ACSR conductor (Aluminum Association, 1974); the curve is valid for conductor sizes ranging from 266.8 to 795 kcmil. A 795 kcmil-26/7 ACSR “Drake” conductor has a breaking strength of 31,500 lb (14,000 kg) and an area of 0.7264 in.<sup>2</sup> (46.9 mm<sup>2</sup>) so that it fails at an average stress of 43,000 psi (30 kg/mm<sup>2</sup>). The stress-strain curve illustrates that when the percent of elongation at a stress is equal to 50% of the conductor’s breaking strength (21,500 psi), the elongation is less than 0.3% or 1.8 ft (0.55 m) in a 600-ft (180 m) span.

Note that the component curves for the steel core and the aluminum stranded outer layers are separated. This separation allows for changes in the relative curve locations as the temperature of the conductor changes.

For the preceding example, with the Drake conductor at a tension of 6300 lb (2860 kg), the length of the conductor in the 600-ft (180 m) span was found to be 0.27 ft longer than the span. This tension corresponds to a stress of 8600 psi (6.05 kg/mm<sup>2</sup>). From the stress-strain curve in Fig. 14.7, this corresponds to an initial elongation of 0.105% (0.63 ft). As in the preceding hand calculation, if the conductor is reduced to zero tension, its unstressed length would be less than the span length.



**Equations for Curves (X = unit strain in %; Y = stress in psi) :**

$$\text{Initial composite: } Y = 4.07 \times 10^{-3} + (1.28 \times 10^{-5}) Y - (1.18 \times 10^{-10}) Y^2 + (5.64 \times 10^{-15}) Y^3$$

$$Y = -512 + (8.617 \times 10^4) X - (1.18 \times 10^4) X^2 - (5.76 \times 10^{-4}) X^3$$

$$\text{Initial Steel: } Y = (37.15 \times 10^3) X$$

$$\text{Initial Aluminum: } Y = -512 + (4.902 \times 10^4) X - (1.18 \times 10^4) X^2 - (5.76 \times 10^{-4}) X^3$$

$$\text{Final Composite: } Y = (107.55 X - 17.65) \times 10^3$$

$$\text{Final Steel: } Y = (38.60 X - 0.65) \times 10^3$$

$$\text{Final Aluminum: } Y = (68.95 X - 17.00) \times 10^3$$

$$\text{6 Month Creep: } Y = (68.75 \times 10^3) X$$

$$\text{1 Year Creep: } Y = (60.60 \times 10^3) X$$

$$\text{10 Year Creep: } Y = (53.45 \times 10^3) X$$

**Test Temperature 70°F to 75°F**

**FIGURE 14.7** Stress-strain curves for 26/7 ACSR.

Figure 14.8 is a stress-strain curve (Aluminum Association, 1974) for an all-aluminum 37-strand conductor ranging in size from 250 kcmil to 1033.5 kcmil. Because the conductor is made entirely of aluminum, there is only one initial and final curve.

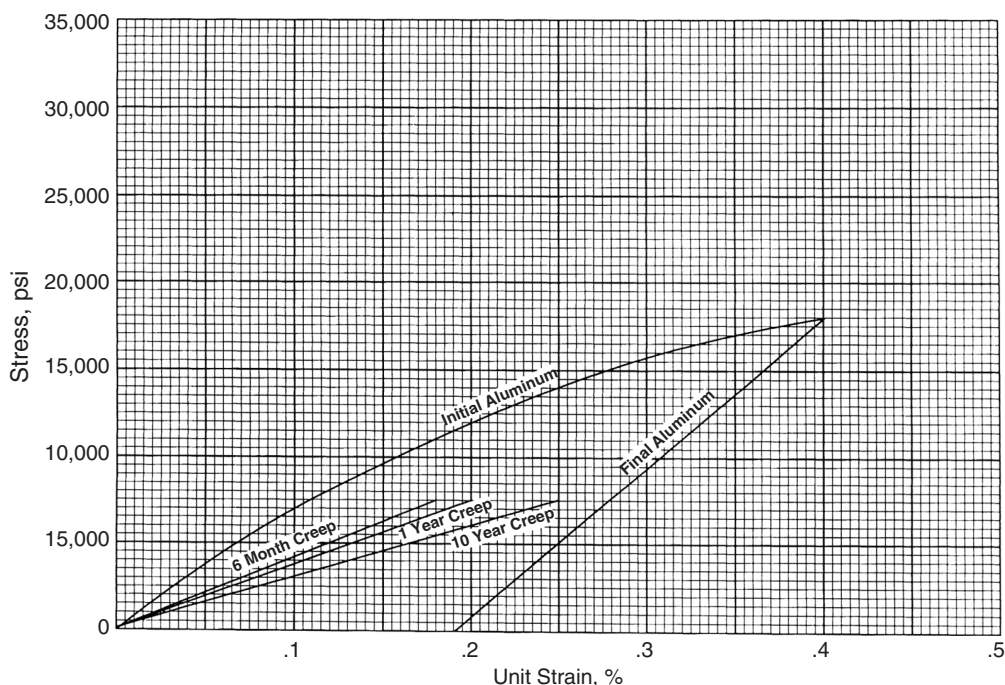
#### 14.3.1.1 Permanent Elongation

Once a conductor has been installed at an initial tension, it can elongate further. Such elongation results from two phenomena: permanent elongation due to high tension levels resulting from ice and wind loads, and creep elongation under everyday tension levels. These types of conductor elongation are discussed in the following sections.

#### 14.3.1.2 Permanent Elongation Due to Heavy Loading

Both Figs. 14.7 and 14.8 indicate that when the conductor is initially installed, it elongates following the initial curve that is not a straight line. If the conductor tension increases to a relatively high level under ice and wind loading, the conductor will elongate. When the wind and ice loads abate, the conductor





**Equations for Curves (X = unit strain in %; Y = stress in psi):**

$$\text{Initial Aluminum: } Y = -5.31 \times 10^{-3} + (1.74 \times 10^{-5}) X - (6.17 \times 10^{-10}) Y^2 + (5.05 \times 10^{-14}) Y^3$$

$$Y = 136 + (7.46 \times 10^4) X - (8.51 \times 10^4) X^2 + (2.33 \times 10^4) X^3$$

$$\text{Final Aluminum: } Y = (85.20 X - 16.14) \times 10^3$$

$$\text{6 Month Creep: } Y = (42.30 \times 10^3) X$$

$$\text{1 Year Creep: } Y = (38.20 \times 10^3) X$$

$$\text{10 Year Creep: } Y = (30.60 \times 10^3) X$$

**Test Temperature 70°F to 75°F**

**FIGURE 14.8** Stress-strain curves for 37-strand AAC.

elongation will reduce along a curve parallel to the final curve, but the conductor will never return to its original length.

For example, refer to Fig. 14.8 and assume that a newly strung 795 kcmil-37 strand AAC “Arbutus” conductor has an everyday tension of 2780 lb. The conductor area is 0.6245 in.<sup>2</sup>, so the everyday stress is 4450 psi and the elongation is 0.062%. Following an extremely heavy ice and wind load event, assume that the conductor stress reaches 18,000 psi. When the conductor tension decreases back to everyday levels, the conductor elongation will be permanently increased by more than 0.2%. Also the sag under everyday conditions will be correspondingly higher, and the tension will be less. In most numerical sag-tension methods, final sag-tensions are calculated for such permanent elongation due to heavy loading conditions.

#### 14.3.1.3 Permanent Elongation at Everyday Tensions (Creep Elongation)

Conductors permanently elongate under tension even if the tension level never exceeds everyday levels. This permanent elongation caused by everyday tension levels is called creep (Aluminum Company of America, 1961). Creep can be determined by long-term laboratory creep tests, the results of which are used to generate creep curves. On stress-strain graphs, creep curves are usually shown for 6-mo, 1-yr, and 10-yr periods. Figure 14.8 shows these typical creep curves for a 37 strand 250.0 through 1033.5 kcmil AAC. In Fig. 14.8 assume that the conductor tension remains constant at the initial stress of 4450 psi. At the intersection of this stress level and the initial elongation curve, 6-month, 1-year, and 10-year creep

curves, the conductor elongation from the initial elongation of 0.062% increases to 0.11%, 0.12%, and 0.15%, respectively. Because of creep elongation, the resulting final sags are greater and the conductor tension is less than the initial values.

Creep elongation in aluminum conductors is quite predictable as a function of time and obeys a simple exponential relationship. Thus, the permanent elongation due to creep at everyday tension can be found for any period of time after initial installation. Creep elongation of copper and steel conductors is much less and is normally ignored.

Permanent increase in conductor length due to heavy load occurrences cannot be predicted at the time that a line is built. The reason for this unpredictability is that the occurrence of heavy ice and wind is random. A heavy ice storm may occur the day after the line is built or may never occur over the life of the line.

### 14.3.2 Sag-Tension Tables

To illustrate the result of typical sag-tension calculations, refer to Tables 14.4 through 14.9 showing initial and final sag-tension data for 795 kcmil-26/7 ACSR “Drake”, 795 kcmil-37 strand AAC “Arbutus”, and 795-kcmil Type 16 “Drake/SDC” conductors in NESC light and heavy loading areas for spans of

**TABLE 14.4** Sag and Tension Data for 795 kcmil-26/7 ACSR “Drake” Conductor

| <div>Span = 600 ft</div> <div>NESC Heavy</div> <div>Loading District</div> |          |                          |          |                            |         |                   |         |             |
|----------------------------------------------------------------------------|----------|--------------------------|----------|----------------------------|---------|-------------------|---------|-------------|
| Creep is <i>not</i> a factor                                               |          |                          |          |                            | Final   |                   | Initial |             |
| Temp, °F                                                                   | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Resultant Weight,<br>lb/ft | Sag, ft | Tension, lb       | Sag, ft | Tension, lb |
| 0                                                                          | 0.50     | 4.00                     | 0.30     | 2.509                      | 11.14   | 10153             | 11.14   | 10153       |
|                                                                            |          |                          |          |                            |         | 5415 Al           |         | 5415 Al     |
|                                                                            |          |                          |          |                            |         | 4738 St           |         | 4738 St     |
| 32                                                                         | 0.50     | 0.00                     | 0.00     | 2.094                      | 44.54   | 8185              | 11.09   | 8512        |
|                                                                            |          |                          |          |                            |         | 3819 Al           |         | 4343 Al     |
|                                                                            |          |                          |          |                            |         | 4366 St           |         | 4169 St     |
| −20                                                                        | 0.00     | 0.00                     | 0.00     | 1.094                      | 6.68    | 7372              | 6.27    | 7855        |
|                                                                            |          |                          |          |                            |         | 3871 Al           |         | 4465 Al     |
|                                                                            |          |                          |          |                            |         | 3501 St           |         | 3390 St     |
| 0                                                                          | 0.00     | 0.00                     | 0.00     | 1.094                      | 7.56    | 6517              | 6.89    | 7147        |
|                                                                            |          |                          |          |                            |         | 3111 Al           |         | 3942 Al     |
|                                                                            |          |                          |          |                            |         | 3406 St           |         | 3205 St     |
| 30                                                                         | 0.00     | 0.00                     | 0.00     | 1.094                      | 8.98    | 5490              | 7.95    | 6197        |
|                                                                            |          |                          |          |                            |         | 2133 Al           |         | 3201 Al     |
|                                                                            |          |                          |          |                            |         | 3357 St           |         | 2996 St     |
| 60                                                                         | 0.00     | 0.00                     | 0.00     | 1.094                      | 10.44   | 4725 <sup>a</sup> | 9.12    | 5402        |
|                                                                            |          |                          |          |                            |         | 1321 Al           |         | 2526 Al     |
|                                                                            |          |                          |          |                            |         | 3404 St           |         | 2875 St     |
| 90                                                                         | 0.00     | 0.00                     | 0.00     | 1.094                      | 11.87   | 4157              | 10.36   | 4759        |
|                                                                            |          |                          |          |                            |         | 634 Al            |         | 1922 Al     |
|                                                                            |          |                          |          |                            |         | 3522 St           |         | 2837 St     |
| 120                                                                        | 0.00     | 0.00                     | 0.00     | 1.094                      | 13.24   | 3727              | 11.61   | 4248        |
|                                                                            |          |                          |          |                            |         | 35 Al             |         | 1379 Al     |
|                                                                            |          |                          |          |                            |         | 3692 St           |         | 2869 St     |
| 167                                                                        | 0.00     | 0.00                     | 0.00     | 1.094                      | 14.29   | 3456              | 13.53   | 3649        |
|                                                                            |          |                          |          |                            |         | 0 Al              |         | 626 Al      |
|                                                                            |          |                          |          |                            |         | 3456 St           |         | 3022 St     |
| 212                                                                        | 0.00     | 0.00                     | 0.00     | 1.094                      | 15.24   | 3241              | 15.24   | 3241        |
|                                                                            |          |                          |          |                            |         | 0 Al              |         | 0 Al        |
|                                                                            |          |                          |          |                            |         | 3241 St           |         | 3239 St     |

<sup>a</sup>Design condition.

**TABLE 14.5** Tension Differences in Adjacent Dead-End Spans

| Conductor: Drake               |          |                          |          |                         |         |             |         |                   |
|--------------------------------|----------|--------------------------|----------|-------------------------|---------|-------------|---------|-------------------|
| 795 kcmil-26/7 ACSR            |          |                          |          |                         |         |             |         |                   |
| Area = 0.7264 in. <sup>2</sup> |          |                          |          |                         |         |             |         |                   |
| Creep <b>is</b> a factor       |          |                          |          |                         |         |             |         |                   |
| NESC Heavy Loading District    |          |                          |          |                         |         |             |         |                   |
|                                |          |                          |          |                         | Final   |             | Initial |                   |
| Temp, °F                       | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Resultant Weight, lb/ft | Sag, ft | Tension, lb | Sag, ft | Tension, lb       |
| 0                              | 0.50     | 4.00                     | 0.30     | 2.509                   | 13.61   | 11318       | 13.55   | 11361             |
| 32                             | 0.50     | 0.00                     | 0.00     | 2.094                   | 13.93   | 9224        | 13.33   | 9643              |
| −20                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 8.22    | 8161        | 7.60    | 8824              |
| 0                              | 0.00     | 0.00                     | 0.00     | 1.094                   | 9.19    | 7301        | 8.26    | 8115              |
| 30                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 10.75   | 6242        | 9.39    | 7142              |
| 60                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 12.36   | 5429        | 10.65   | 6300 <sup>a</sup> |
| 90                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 13.96   | 4809        | 11.99   | 5596              |
| 120                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 15.52   | 4330        | 13.37   | 5020              |
| 167                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 16.97   | 3960        | 15.53   | 4326              |
| 212                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 18.04   | 3728        | 17.52   | 3837              |

<sup>a</sup>Design condition.

| Conductor: Drake               |          |                          |          |                         |         |             |         |                   |
|--------------------------------|----------|--------------------------|----------|-------------------------|---------|-------------|---------|-------------------|
| 795 kcmil-26/7 ACSR            |          |                          |          |                         |         |             |         |                   |
| Area = 0.7264 in. <sup>2</sup> |          |                          |          |                         |         |             |         |                   |
| Creep is <b>not</b> a factor   |          |                          |          |                         |         |             |         |                   |
| NESC Heavy Loading District    |          |                          |          |                         |         |             |         |                   |
|                                |          |                          |          |                         | Final   |             | Initial |                   |
| Temp, °F                       | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Resultant Weight, lb/ft | Sag, ft | Tension, lb | Sag, ft | Tension, lb       |
| 0                              | 0.50     | 4.00                     | 0.30     | 2.509                   | 25.98   | 12116       | 25.98   | 12116             |
| 32                             | 0.50     | 0.00                     | 0.00     | 2.094                   | 26.30   | 9990        | 25.53   | 10290             |
| −20                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 18.72   | 7318        | 17.25   | 7940              |
| 0                              | 0.00     | 0.00                     | 0.00     | 1.094                   | 20.09   | 6821        | 18.34   | 7469              |
| 30                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 22.13   | 6197        | 20.04   | 6840              |
| 60                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 24.11   | 5689        | 21.76   | 6300 <sup>a</sup> |
| 90                             | 0.00     | 0.00                     | 0.00     | 1.094                   | 26.04   | 5271        | 23.49   | 5839              |
| 120                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 27.89   | 4923        | 25.20   | 5444              |
| 167                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 30.14   | 4559        | 27.82   | 4935              |
| 212                            | 0.00     | 0.00                     | 0.00     | 1.094                   | 31.47   | 4369        | 30.24   | 4544              |

<sup>a</sup>Design condition.

1000 and 300 ft. Typical tension constraints of 15% final unloaded at 60°F, 25% initial unloaded at 60°F, and 60% initial at maximum loading are used.

With most sag-tension calculation methods, final sags are calculated for both heavy ice/wind load and for creep elongation. The final sag-tension values reported to the user are those with the greatest increase in sag.

#### 14.3.2.1 Initial vs. Final Sags and Tensions

Rather than calculate the line sag as a function of time, most sag-tension calculations are determined based on initial and final loading conditions. Initial sags and tensions are simply the sags and tensions at the time the line is built. Final sags and tensions are calculated if (1) the specified ice and wind loading has occurred, and (2) the conductor has experienced 10 years of creep elongation at a conductor temperature of 60°F at the user-specified initial tension.

**TABLE 14.6** Sag and Tension Data for 795 kcmil-26/7 ACSR “Drake” 600-ft Ruling Span

| Conductor: Drake                   |          |                          |          |                            |         |                   |         |             |
|------------------------------------|----------|--------------------------|----------|----------------------------|---------|-------------------|---------|-------------|
| 795 kcmil-26/7 ACSR                |          |                          |          |                            |         |                   |         |             |
| Area = 0.7264 in. <sup>2</sup>     |          |                          |          |                            |         |                   |         |             |
| Creep is <b>not</b> a factor       |          |                          |          |                            |         |                   |         |             |
| <i>NESC Heavy Loading District</i> |          |                          |          |                            |         |                   |         |             |
| Temp, °F                           | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Resultant Weight,<br>lb/ft | Final   |                   | Initial |             |
|                                    |          |                          |          |                            | Sag, ft | Tension, lb       | Sag, ft | Tension, lb |
| 0                                  | 0.50     | 4.00                     | 0.30     | 2.509                      | 11.14   | 10153             | 11.14   | 10153       |
| 32                                 | 0.50     | 0.00                     | 0.00     | 2.094                      | 11.54   | 8185              | 11.09   | 8512        |
| −20                                | 0.00     | 0.00                     | 0.00     | 1.094                      | 6.68    | 7372              | 6.27    | 7855        |
| 0                                  | 0.00     | 0.00                     | 0.00     | 1.094                      | 7.56    | 6517              | 6.89    | 7147        |
| 30                                 | 0.00     | 0.00                     | 0.00     | 1.094                      | 8.98    | 5490              | 7.95    | 6197        |
| 60                                 | 0.00     | 0.00                     | 0.00     | 1.094                      | 10.44   | 4725 <sup>a</sup> | 9.12    | 5402        |
| 90                                 | 0.00     | 0.00                     | 0.00     | 1.094                      | 11.87   | 4157              | 10.36   | 4759        |
| 120                                | 0.00     | 0.00                     | 0.00     | 1.094                      | 13.24   | 3727              | 11.61   | 4248        |
| 167                                | 0.00     | 0.00                     | 0.00     | 1.094                      | 14.29   | 3456              | 13.53   | 3649        |
| 212                                | 0.00     | 0.00                     | 0.00     | 1.094                      | 15.24   | 3241              | 15.24   | 3241        |

<sup>a</sup>Design condition.**TABLE 14.7** Stringing Sag Table for 795 kcmil-26/7 ACSR “Drake” 600-ft Ruling Span

| <b>600-ft Ruling Span</b>              |             |             |             |             |             |             |             |             |             |
|----------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Controlling Design Condition:          |             |             |             |             |             |             |             |             |             |
| 15% RBS at 60°F, No Ice or Wind, Final |             |             |             |             |             |             |             |             |             |
| <i>NESC Heavy Load District</i>        |             |             |             |             |             |             |             |             |             |
| Horizontal                             | 6493        | 6193        | 5910        | 5645        | 5397        | 5166        | 4952        | 4753        | 4569        |
| Tension, lb                            | 20          | 30          | 40          | 50          | 60          | 70          | 80          | 90          | 100         |
| Temp, °F Spans                         | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. | Sag, ft-in. |
| 400                                    | 3 - 4       | 3 - 6       | 3 - 8       | 3 - 11      | 4 - 1       | 4 - 3       | 4 - 5       | 4 - 7       | 4 - 9       |
| 410                                    | 3 - 6       | 3 - 9       | 3 - 11      | 4 - 1       | 4 - 3       | 4 - 5       | 4 - 8       | 4 - 10      | 5 - 0       |
| 420                                    | 3 - 9       | 3 - 11      | 4 - 1       | 4 - 3       | 4 - 6       | 4 - 8       | 4 - 10      | 5 - 1       | 5 - 3       |
| 430                                    | 3 - 11      | 4 - 1       | 4 - 3       | 4 - 6       | 4 - 8       | 4 - 11      | 5 - 1       | 5 - 4       | 5 - 6       |
| 440                                    | 4 - 1       | 4 - 3       | 4 - 6       | 4 - 8       | 4 - 11      | 5 - 2       | 5 - 4       | 5 - 7       | 5 - 10      |
| 450                                    | 4 - 3       | 4 - 6       | 4 - 8       | 4 - 11      | 5 - 2       | 5 - 4       | 5 - 7       | 5 - 10      | 6 - 1       |
| 460                                    | 4 - 5       | 4 - 8       | 4 - 11      | 5 - 2       | 5 - 4       | 5 - 7       | 5 - 10      | 6 - 1       | 6 - 4       |
| 470                                    | 4 - 8       | 4 - 11      | 5 - 1       | 5 - 4       | 5 - 7       | 5 - 10      | 6 - 1       | 6 - 4       | 6 - 7       |
| 480                                    | 4 - 10      | 5 - 1       | 5 - 4       | 5 - 7       | 5 - 10      | 6 - 1       | 6 - 4       | 6 - 8       | 6 - 11      |
| 490                                    | 5 - 1       | 5 - 4       | 5 - 7       | 5 - 10      | 6 - 1       | 6 - 4       | 6 - 8       | 6 - 11      | 7 - 2       |
| 500                                    | 5 - 3       | 5 - 6       | 5 - 9       | 6 - 1       | 6 - 4       | 6 - 7       | 6 - 11      | 7 - 2       | 7 - 6       |
| 510                                    | 5 - 6       | 5 - 9       | 6 - 0       | 6 - 4       | 6 - 7       | 6 - 11      | 7 - 2       | 7 - 6       | 7 - 9       |
| 520                                    | 5 - 8       | 6 - 0       | 6 - 3       | 6 - 7       | 6 - 10      | 7 - 2       | 7 - 6       | 7 - 9       | 8 - 1       |
| 530                                    | 5 - 11      | 6 - 2       | 6 - 6       | 6 - 10      | 7 - 1       | 7 - 5       | 7 - 9       | 8 - 1       | 8 - 5       |
| 540                                    | 6 - 2       | 6 - 5       | 6 - 9       | 7 - 1       | 7 - 5       | 7 - 9       | 8 - 1       | 8 - 5       | 8 - 9       |
| 550                                    | 6 - 4       | 6 - 8       | 7 - 0       | 7 - 4       | 7 - 8       | 8 - 0       | 8 - 4       | 8 - 8       | 9 - 1       |
| 560                                    | 6 - 7       | 6 - 11      | 7 - 3       | 7 - 7       | 7 - 11      | 8 - 4       | 8 - 8       | 9 - 0       | 9 - 5       |
| 570                                    | 6 - 10      | 7 - 2       | 7 - 6       | 7 - 10      | 8 - 3       | 8 - 7       | 9 - 0       | 9 - 4       | 9 - 9       |
| 580                                    | 7 - 1       | 7 - 5       | 7 - 9       | 8 - 2       | 8 - 6       | 8 - 11      | 9 - 4       | 9 - 8       | 10 - 1      |
| 590                                    | 7 - 4       | 7 - 8       | 8 - 1       | 8 - 5       | 8 - 10      | 9 - 3       | 9 - 7       | 10 - 0      | 10 - 5      |
| 600                                    | 7 - 7       | 7 - 11      | 8 - 4       | 8 - 9       | 9 - 1       | 9 - 6       | 9 - 11      | 10 - 4      | 10 - 9      |
| 610                                    | 7 - 1       | 8 - 3       | 8 - 7       | 9 - 0       | 9 - 5       | 9 - 10      | 10 - 3      | 10 - 9      | 11 - 2      |
| 620                                    | 8 - 1       | 8 - 6       | 8 - 11      | 9 - 4       | 9 - 9       | 10 - 2      | 10 - 7      | 11 - 1      | 11 - 6      |
| 630                                    | 8 -         | 8 - 9       | 9 - 2       | 9 - 7       | 10 - 1      | 10 - 6      | 11 - 0      | 11 - 5      | 11 - 11     |
| 640                                    | 8 - 8       | 9 - 1       | 9 - 6       | 9 - 11      | 10 - 5      | 10 - 10     | 11 - 4      | 11 - 9      | 12 - 3      |
| 650                                    | 8 - 11      | 9 - 4       | 9 - 9       | 10 - 3      | 10 - 9      | 11 - 2      | 11 - 8      | 12 - 2      | 12 - 8      |
| 660                                    | 9 - 2       | 9 - 7       | 10 - 1      | 10 - 7      | 11 - 1      | 11 - 6      | 12 - 0      | 12 - 6      | 13 - 1      |
| 670                                    | 9 - 5       | 9 - 11      | 10 - 5      | 10 - 11     | 11 - 5      | 11 - 11     | 12 - 5      | 12 - 11     | 13 - 5      |
| 680                                    | 9 - 9       | 10 - 3      | 10 - 8      | 11 - 2      | 11 - 9      | 12 - 3      | 12 - 9      | 13 - 4      | 13 - 10     |
| 690                                    | 10 - 0      | 10 - 6      | 11 - 0      | 11 - 6      | 12 - 1      | 12 - 7      | 13 - 2      | 13 - 8      | 14 - 3      |
| 700                                    | 10 - 4      | 10 - 10     | 11 - 4      | 11 - 11     | 12 - 5      | 13 - 0      | 13 - 6      | 14 - 1      | 14 - 8      |

**TABLE 14.8** Time-Sag Table for Stopwatch Method

| Return of Wave |                  |                  |             |                  |                  |             |                  |                  |             |                  |                  |
|----------------|------------------|------------------|-------------|------------------|------------------|-------------|------------------|------------------|-------------|------------------|------------------|
| Sag,<br>in.    | 3rd Time,<br>sec | 5th Time,<br>sec | Sag,<br>in. | 3rd Time,<br>sec | 5th Time,<br>sec | Sag,<br>in. | 3rd Time,<br>sec | 5th Time,<br>sec | Sag,<br>in. | 3rd Time,<br>sec | 5th Time,<br>sec |
| 5              | 1.9              | 3.2              | 55          | 6.4              | 10.7             | 105         | 8.8              | 14.7             | 155         | 10.7             | 17.9             |
| 6              | 2.1              | 3.5              | 56          | 6.5              | 10.8             | 106         | 8.9              | 14.8             | 156         | 10.8             | 18.0             |
| 7              | 2.3              | 3.8              | 57          | 6.5              | 10.9             | 107         | 8.9              | 14.9             | 157         | 10.8             | 18.0             |
| 8              | 2.4              | 4.1              | 58          | 6.6              | 11.1             | 109         | 9.0              | 15.0             | 158         | 10.9             | 18.1             |
| 9              | 2.6              | 4.3              | 59          | 6.6              | 11.1             | 109         | 9.0              | 15.0             | 159         | 10.9             | 18.1             |
| 10             | 2.7              | 4.6              | 60          | 6.7              | 11.1             | 110         | 9.1              | 15.1             | 160         | 10.9             | 18.2             |
| 11             | 2.9              | 4.8              | 61          | 6.7              | 11.2             | 111         | 9.1              | 15.2             | 161         | 11.0             | 18.2             |
| 12             | 3.0              | 5.0              | 62          | 6.8              | 11.3             | 112         | 9.1              | 15.2             | 162         | 11.0             | 18.2             |
| 13             | 3.1              | 5.2              | 63          | 6.9              | 11.4             | 113         | 9.2              | 15.3             | 163         | 11.0             | 18.4             |
| 14             | 3.2              | 5.4              | 64          | 6.9              | 11.5             | 114         | 9.2              | 15.4             | 164         | 11.1             | 18.4             |
| 15             | 3.3              | 5.6              | 65          | 7.0              | 11.6             | 115         | 9.3              | 15.4             | 165         | 11.1             | 18.5             |
| 16             | 3.5              | 5.8              | 66          | 7.0              | 11.7             | 116         | 9.3              | 15.5             | 166         | 11.1             | 18.5             |
| 17             | 3.6              | 5.9              | 67          | 7.1              | 11.8             | 117         | 9.3              | 15.6             | 167         | 11.2             | 18.6             |
| 18             | 3.7              | 6.1              | 68          | 7.1              | 11.9             | 118         | 9.4              | 15.6             | 168         | 11.2             | 18.7             |
| 19             | 3.8              | 6.3              | 69          | 7.2              | 12.0             | 119         | 9.4              | 15.7             | 169         | 11.2             | 18.7             |
| 20             | 3.9              | 6.4              | 70          | 7.2              | 12.0             | 120         | 9.5              | 15.8             | 170         | 11.3             | 18.8             |
| 21             | 4.0              | 6.6              | 71          | 7.3              | 12.1             | 121         | 9.5              | 15.8             | 171         | 11.3             | 18.8             |
| 22             | 4.0              | 6.7              | 72          | 7.3              | 12.2             | 122         | 9.5              | 15.9             | 172         | 11.3             | 18.9             |
| 23             | 4.1              | 6.9              | 73          | 7.4              | 12.3             | 123         | 9.6              | 16.0             | 173         | 11.4             | 18.9             |
| 24             | 4.2              | 7.0              | 74          | 7.4              | 12.4             | 124         | 9.6              | 16.0             | 174         | 11.4             | 19.0             |
| 25             | 4.3              | 7.2              | 75          | 7.5              | 12.5             | 125         | 9.7              | 16.1             | 175         | 11.4             | 19.0             |
| 26             | 4.4              | 7.3              | 76          | 7.5              | 12.5             | 126         | 9.7              | 16.2             | 176         | 11.4             | 19.1             |
| 27             | 4.5              | 7.5              | 77          | 7.6              | 12.6             | 127         | 9.7              | 16.2             | 177         | 11.5             | 19.1             |
| 28             | 4.6              | 7.6              | 78          | 7.6              | 12.7             | 128         | 9.8              | 16.3             | 178         | 11.5             | 19.2             |
| 29             | 4.6              | 7.7              | 79          | 7.7              | 12.8             | 129         | 9.8              | 16.3             | 179         | 11.5             | 19.3             |
| 30             | 4.7              | 7.9              | 80          | 7.7              | 12.9             | 130         | 9.8              | 16.4             | 180         | 11.6             | 19.3             |
| 31             | 4.8              | 8.0              | 81          | 7.8              | 13.0             | 131         | 9.9              | 16.5             | 181         | 11.6             | 19.4             |
| 32             | 4.9              | 8.1              | 82          | 7.8              | 13.0             | 132         | 9.9              | 16.5             | 182         | 11.6             | 19.4             |
| 33             | 5.0              | 8.3              | 83          | 7.9              | 13.1             | 133         | 10.0             | 16.6             | 183         | 11.7             | 19.5             |
| 34             | 5.0              | 8.4              | 84          | 7.9              | 13.2             | 134         | 10.0             | 16.7             | 184         | 11.7             | 19.5             |
| 35             | 5.1              | 8.5              | 85          | 8.0              | 13.3             | 135         | 10.0             | 16.7             | 185         | 11.7             | 19.6             |
| 36             | 5.2              | 8.6              | 86          | 8.0              | 13.3             | 136         | 10.1             | 16.8             | 186         | 11.8             | 19.6             |
| 37             | 5.3              | 8.8              | 87          | 8.1              | 13.4             | 137         | 10.1             | 16.8             | 187         | 11.8             | 19.7             |
| 38             | 5.3              | 8.9              | 88          | 8.1              | 13.5             | 138         | 10.1             | 16.9             | 188         | 11.8             | 19.7             |
| 39             | 5.4              | 9.0              | 89          | 8.1              | 13.6             | 139         | 10.2             | 17.0             | 189         | 11.9             | 19.8             |
| 40             | 5.5              | 9.1              | 90          | 8.2              | 13.7             | 140         | 10.2             | 17.0             | 190         | 11.9             | 19.8             |
| 41             | 5.5              | 9.2              | 91          | 8.2              | 13.7             | 141         | 10.3             | 17.1             | 191         | 11.9             | 19.9             |
| 42             | 5.6              | 9.3              | 92          | 8.3              | 13.8             | 142         | 10.3             | 17.1             | 192         | 12.0             | 19.9             |
| 43             | 5.7              | 9.4              | 93          | 8.3              | 13.9             | 143         | 10.3             | 17.2             | 193         | 12.0             | 20.0             |
| 44             | 5.7              | 9.5              | 94          | 8.4              | 14.0             | 144         | 10.4             | 17.3             | 194         | 12.0             | 20.0             |
| 45             | 5.8              | 9.7              | 95          | 8.4              | 14.0             | 145         | 10.4             | 17.3             | 195         | 12.1             | 20.1             |
| 46             | 5.9              | 9.8              | 96          | 8.5              | 14.1             | 146         | 10.4             | 17.4             | 196         | 12.1             | 20.1             |
| 47             | 5.9              | 9.9              | 97          | 8.5              | 14.2             | 147         | 10.5             | 17.4             | 197         | 12.1             | 20.2             |
| 48             | 6.0              | 10.0             | 98          | 8.5              | 14.2             | 148         | 10.5             | 17.5             | 198         | 12.1             | 20.0             |
| 49             | 6.0              | 10.1             | 99          | 8.6              | 14.3             | 149         | 10.5             | 17.6             | 199         | 12.2             | 20.3             |
| 50             | 6.1              | 10.2             | 100         | 8.6              | 14.4             | 150         | 10.6             | 17.6             | 200         | 12.2             | 20.3             |
| 51             | 6.2              | 10.3             | 101         | 8.7              | 14.5             | 151         | 10.6             | 17.7             | 201         | 12.2             | 20.4             |
| 52             | 6.2              | 10.4             | 102         | 8.7              | 14.5             | 152         | 10.6             | 17.7             | 202         | 12.3             | 20.5             |
| 53             | 6.3              | 10.5             | 103         | 8.8              | 14.6             | 153         | 10.7             | 17.8             | 203         | 12.3             | 20.5             |
| 54             | 6.3              | 10.6             | 104         | 8.8              | 14.7             | 154         | 10.7             | 17.9             | 204         | 12.3             | 20.6             |

Note: To calculate the time of return of other waves, multiply the time in seconds for one wave return by the number of wave returns or, more simply, select the combination of values from the table that represents the number of wave returns desired. For example, the time of return of the 8th wave is the sum of the 3rd and 5th, while for the 10th wave it is twice the time of the 5<sup>th</sup>.

The approximate formula giving the relationship between sag and time is given as:

$$D = 12.075 \left( \frac{T}{N} \right)^2 \text{ (inches)}$$

where  $D$  = sag, in.

$T$  = time, sec

$N$  = number of return waves counted

**TABLE 14.9** Typical Sag and Tension Data 795 kcmil-26/7 ACSR “Drake,” 300- and 1000-ft Spans

Conductor: Drake

795 kcmil-26/7 ACSR

Area = 0.7264 in.<sup>2</sup>Creep *is* a factor**Span = 300 ft***NESC Heavy Loading District*

| Temp,<br>°F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final      |                   | Initial    |                |
|-------------|----------|-----------------------------|----------|------------------|------------|-------------------|------------|----------------|
|             |          |                             |          |                  | Sag,<br>ft | Tension,<br>lb    | Sag,<br>ft | Tension,<br>lb |
| 30          | 0.00     | 9.00                        | 0.05     | 1.424            | 2.37       | 6769              | 2.09       | 7664           |
| 30          | 0.00     | 0.00                        | 0.00     | 1.094            | 1.93       | 6364              | 1.66       | 7404           |
| 60          | 0.00     | 0.00                        | 0.00     | 1.094            | 2.61       | 4725 <sup>a</sup> | 2.04       | 6033           |
| 90          | 0.00     | 0.00                        | 0.00     | 1.094            | 3.46       | 3556              | 2.57       | 4792           |
| 120         | 0.00     | 0.00                        | 0.00     | 1.094            | 1.00       | 3077              | 3.25       | 3785           |
| 167         | 0.00     | 0.00                        | 0.00     | 1.094            | 4.60       | 2678              | 4.49       | 2746           |
| 212         | 0.00     | 0.00                        | 0.00     | 1.094            | 5.20       | 2371              | 5.20       | 2371           |

<sup>a</sup> Design condition.

Conductor: Drake

795 kcmil-26/7 ACSR

Area = 0.7264 in.<sup>2</sup>Creep *is* a factor**Span = 1000 ft***NESC Heavy Loading District*

| Temp,<br>°F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final      |                   | Initial    |                |
|-------------|----------|-----------------------------|----------|------------------|------------|-------------------|------------|----------------|
|             |          |                             |          |                  | Sag,<br>ft | Tension,<br>lb    | Sag,<br>ft | Tension,<br>lb |
| 30          | 0.00     | 9.00                        | 0.05     | 1.424            | 28.42      | 6290              | 27.25      | 6558           |
| 30          | 0.00     | 0.00                        | 0.00     | 1.094            | 27.26      | 5036              | 25.70      | 5339           |
| 60          | 0.00     | 0.00                        | 0.00     | 1.094            | 29.07      | 4725 <sup>a</sup> | 27.36      | 5018           |
| 90          | 0.00     | 0.00                        | 0.00     | 1.094            | 30.82      | 4460              | 28.98      | 4740           |
| 120         | 0.00     | 0.00                        | 0.00     | 1.094            | 32.50      | 4232              | 30.56      | 4498           |
| 167         | 0.00     | 0.00                        | 0.00     | 1.094            | 34.49      | 3990              | 32.56      | 4175           |
| 212         | 0.00     | 0.00                        | 0.00     | 1.094            | 35.75      | 3851              | 35.14      | 3917           |

<sup>a</sup> Design condition.

Note: **Calculations based on:** (1) NESC Light Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 30°F; b. Initial Unloaded – 25% RBS @ 60°F; c. Final Unloaded – 15% RBS @ 60°F.

### 14.3.2.2 Special Aspects of ACSR Sag-Tension Calculations

Sag-tension calculations with ACSR conductors are more complex than such calculations with AAC, AAAC, or ACAR conductors. The complexity results from the different behavior of steel and aluminum strands in response to tension and temperature. Steel wires do not exhibit creep elongation or plastic elongation in response to high tensions. Aluminum wires do creep and respond plastically to high stress levels. Also, they elongate twice as much as steel wires do in response to changes in temperature.

Table 14.10 presents various initial and final sag-tension values for a 600-ft span of a Drake ACSR conductor under heavy loading conditions. Note that the tension in the aluminum and steel components is shown separately. In particular, some other useful observations are:

1. At 60°F, without ice or wind, the tension level in the aluminum strands decreases with time as the strands permanently elongate due to creep or heavy loading.
2. Both initially and finally, the tension level in the aluminum strands decreases with increasing temperature reaching zero tension at 212°F and 167°F for initial and final conditions, respectively.
3. At the highest temperature (212°F), where all the tension is in the steel core, the initial and final sag-tensions are nearly the same, illustrating that the steel core does not permanently elongate in response to time or high tension.

**TABLE 14.10** Typical Sag and Tension Data 795 kcmil-26/7 ACSR “Drake,” 300- and 1000-ft Spans

Conductor: Drake  
 795 kcmil-26/7 ACSR/SD  
 Area = 0.7264 in.<sup>2</sup>  
 Creep **is** a factor

**Span = 300 ft**

*NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 0        | 0.50     | 4.00                        | 0.30     | 2.509            | 2.91    | 9695              | 2.88    | 9802           |
| 32       | 0.50     | 0.00                        | 0.00     | 2.094            | 3.13    | 7528              | 2.88    | 8188           |
| –20      | 0.00     | 0.00                        | 0.00     | 1.094            | 1.26    | 9733              | 1.26    | 9756           |
| 0        | 0.00     | 0.00                        | 0.00     | 1.094            | 1.48    | 8327              | 1.40    | 8818           |
| 30       | 0.00     | 0.00                        | 0.00     | 1.094            | 1.93    | 6364              | 1.66    | 7404           |
| 60       | 0.00     | 0.00                        | 0.00     | 1.094            | 2.61    | 4725 <sup>a</sup> | 2.04    | 6033           |
| 90       | 0.00     | 0.00                        | 0.00     | 1.094            | 3.46    | 3556              | 2.57    | 4792           |
| 120      | 0.00     | 0.00                        | 0.00     | 1.094            | 4.00    | 3077              | 3.25    | 3785           |
| 167      | 0.00     | 0.00                        | 0.00     | 1.094            | 4.60    | 2678              | 4.49    | 2746           |
| 212      | 0.00     | 0.00                        | 0.00     | 1.094            | 5.20    | 2371              | 5.20    | 2371           |

<sup>a</sup>Design condition.

Conductor: Drake  
 795 kcmil-26/7 ACSR  
 Area = 0.7264 in.<sup>2</sup>  
 Creep is **not** a factor

**Span = 1000 ft**

*NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 0        | 0.50     | 4.00                        | 0.30     | 2.509            | 30.07   | 10479             | 30.07   | 10479          |
| 32       | 0.50     | 0.00                        | 0.00     | 2.094            | 30.56   | 8607              | 29.94   | 8785           |
| –20      | 0.00     | 0.00                        | 0.00     | 1.094            | 24.09   | 5694              | 22.77   | 6023           |
| 0        | 0.00     | 0.00                        | 0.00     | 1.094            | 25.38   | 5406              | 23.90   | 5738           |
| 30       | 0.00     | 0.00                        | 0.00     | 1.094            | 27.26   | 5036              | 25.59   | 5362           |
| 60       | 0.00     | 0.00                        | 0.00     | 1.094            | 29.07   | 4725 <sup>a</sup> | 27.25   | 5038           |
| 90       | 0.00     | 0.00                        | 0.00     | 1.094            | 30.82   | 4460              | 28.87   | 4758           |
| 120      | 0.00     | 0.00                        | 0.00     | 1.094            | 32.50   | 4232              | 30.45   | 4513           |
| 167      | 0.00     | 0.00                        | 0.00     | 1.094            | 34.36   | 4005              | 32.85   | 4187           |
| 212      | 0.00     | 0.00                        | 0.00     | 1.094            | 35.62   | 3865              | 35.05   | 3928           |

<sup>a</sup>Design condition.

*Note: Calculations based on:* (1) NESC Heavy Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 0°F; b. Initial Unloaded – 25% RBS @ 60°F; c. Final Unloaded – 15% RBS @ 60°F.

## 14.4 Ruling Span Concept

Transmission lines are normally designed in line sections with each end of the line section terminated by a strain structure that allows no longitudinal (along the line) movement of the conductor (Winkelman, 1959). Structures within each line section are typically suspension structures that support the conductor vertically, but allow free movement of the conductor attachment point either longitudinally or transversely.

### 14.4.1 Tension Differences for Adjacent Dead-End Spans

Table 14.11 contains initial and final sag-tension data for a 700-ft and a 1000-ft dead-end span when a Drake ACSR conductor is initially installed to the same 6300-lb tension limits at 60°F. Note that the

**TABLE 14.11** Typical Sag and Tension Data 795 kcmil-Type 16 ACSR/SD, 300- and 1000-ft Spans

Conductor: Drake

795 kcmil-Type 16 ACSR/SD

Area = 0.7261 in.<sup>2</sup>Creep *is* a factor**Span = 300 ft***NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                | Initial |                    |
|----------|----------|-----------------------------|----------|------------------|---------|----------------|---------|--------------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb | Sag, ft | Tension,<br>lb     |
| 30       | 0.00     | 9.00                        | 0.05     | 1.409            | 1.59    | 9980           | 1.31    | 12373              |
| 30       | 0.00     | 0.00                        | 0.00     | 1.093            | 1.26    | 9776           | 1.03    | 11976              |
| 60       | 0.00     | 0.00                        | 0.00     | 1.093            | 1.60    | 7688           | 1.16    | 10589 <sup>a</sup> |
| 90       | 0.00     | 0.00                        | 0.00     | 1.093            | 2.12    | 5806           | 1.34    | 9159               |
| 120      | 0.00     | 0.00                        | 0.00     | 1.093            | 2.69    | 4572           | 1.59    | 7713               |
| 167      | 0.00     | 0.00                        | 0.00     | 1.093            | 3.11    | 3957           | 2.22    | 5545               |
| 212      | 0.00     | 0.00                        | 0.00     | 1.093            | 3.58    | 3435           | 3.17    | 3877               |

<sup>a</sup> Design condition.

Conductor: Drake

795 kcmil-Type 16 ACSR/SD

Area = 0.7261 in.<sup>2</sup>Creep *is* a factor**Span = 1000 ft***NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 30       | 0.00     | 9.00                        | 0.05     | 1.409            | 17.21   | 10250             | 15.10   | 11676          |
| 30       | 0.00     | 0.00                        | 0.00     | 1.093            | 15.22   | 8988              | 12.69   | 10779          |
| 60       | 0.00     | 0.00                        | 0.00     | 1.093            | 17.21   | 7950 <sup>a</sup> | 13.98   | 9780           |
| 90       | 0.00     | 0.00                        | 0.00     | 1.093            | 19.26   | 7108              | 15.44   | 8861           |
| 120      | 0.00     | 0.00                        | 0.00     | 1.093            | 21.31   | 6428              | 17.03   | 8037           |
| 167      | 0.00     | 0.00                        | 0.00     | 1.093            | 24.27   | 5647              | 19.69   | 6954           |
| 212      | 0.00     | 0.00                        | 0.00     | 1.093            | 25.62   | 5352              | 22.32   | 6136           |

<sup>a</sup> Design condition.

**Note: Calculations based on:** (1) NESC Light Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 30°F; b. Initial Unloaded – 25% RBS @ 60°F; c. Final Unloaded – 15% RBS @ 60°F.

difference between the initial and final limits at 60°F is approximately 460 lb. Even the initial tension (equal at 60°F) differs by almost 900 lb at –20°F and 600 lb at 167°F.

#### 14.4.2 Tension Equalization by Suspension Insulators

At a typical suspension structure, the conductor is supported vertically by a suspension insulator assembly, but allowed to move freely in the direction of the conductor axis. This conductor movement is possible due to insulator swing along the conductor axis. Changes in conductor tension between spans, caused by changes in temperature, load, and time, are normally equalized by insulator swing, eliminating horizontal tension differences across suspension structures.

#### 14.4.3 Ruling Span Calculation

Sag-tension can be found for a series of suspension spans in a line section by use of the ruling span concept (Ehrenberg, 1935; Winkelman, 1959). The ruling span (RS) for the line section is defined by the following equation:

$$RS = \sqrt{\frac{S_1^3 + S_2^3 + \cdots + S_n^3}{S_1 + S_2 + \cdots + S_n}} \quad (14.26)$$



where  $RS$  = Ruling span for the line section containing  $n$  suspension spans

$S_1$  = Span length of first suspension span

$S_2$  = Span length of second suspension span

$S_n$  = Span length of  $n$ th suspension span

Alternatively, a generally satisfactory method for estimating the ruling span is to take the sum of the average suspension span length plus two-thirds of the difference between the maximum span and the average span. However, some judgment must be exercised in using this method because a large difference between the average and maximum span may cause a substantial error in the ruling span value.

As discussed, suspension spans are supported by suspension insulators that are free to move in the direction of the conductor axis. This freedom of movement allows the tension in each suspension span to be assumed to be the same and equal to that calculated for the ruling span. This assumption is valid for the suspension spans and ruling span under the same conditions of temperature and load, for both initial and final sags. For level spans, sag in each suspension span is given by the parabolic sag equation:

$$D_i = \frac{w(S_i^2)}{8H_{RS}} \quad (14.27)$$

where  $D_i$  = sag in the  $i$ th span

$S_i$  = span length of the  $i$ th span

$H_{RS}$  = tension from ruling span sag-tension calculations

The sag in level suspension spans may also be calculated using the ratio:

where  $D_{RS}$  = sag in ruling span

Suspension spans vary in length, though typically not over a large range. Conductor temperature during sagging varies over a range considerably smaller than that used for line design purposes.

If the sag in any suspension span exceeds approximately 5% of the span length, a correction factor should be added to the sags obtained from the above equation or the sag should be calculated using catenary Eq. (14.29). This correction factor may be calculated as follows:

$$Correction = D^2 \frac{w}{6H} \quad (14.28)$$

where  $D$  = sag obtained from parabolic equation

$w$  = weight of conductor, lb/ft

$H$  = horizontal tension, lb

The catenary equation for calculating the sag in a suspension or stringing span is:

$$Sag = \frac{H}{w} \left( \cosh \frac{Sw}{2H} - 1 \right) \quad (14.29)$$

where  $S$  = span length, ft

$H$  = horizontal tension, lb

$w$  = resultant weight, lb/ft

#### 14.4.4 Stringing Sag Tables

Conductors are typically installed in line section lengths consisting of multiple spans. The conductor is pulled from the conductor reel at a point near one strain structure progressing through travelers attached to each suspension structure to a point near the next strain structure. After stringing, the

**TABLE 14.12** Typical Sag and Tension Data 795 kcmil-Type 16 ACSR/SD, 300- and 1000-ft Span

Conductor: Drake

795 kcmil-Type 16 ACSR/SD

Area = 0.7261 in.<sup>2</sup>Creep *is* a factor**Span = 300 ft***NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                | Initial |                    |
|----------|----------|-----------------------------|----------|------------------|---------|----------------|---------|--------------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb | Sag, ft | Tension,<br>lb     |
| 0        | 0.50     | 4.00                        | 0.30     | 2.486            | 2.19    | 12774          | 2.03    | 13757              |
| 32       | 0.50     | 0.00                        | 0.00     | 2.074            | 2.25    | 10377          | 1.90    | 12256              |
| −20      | 0.00     | 0.00                        | 0.00     | 1.093            | .91     | 13477          | .87     | 14156              |
| 0        | 0.00     | 0.00                        | 0.00     | 1.093            | 1.03    | 11962          | .92     | 13305              |
| 30       | 0.00     | 0.00                        | 0.00     | 1.093            | 1.26    | 9776           | 1.03    | 11976              |
| 60       | 0.00     | 0.00                        | 0.00     | 1.093            | 1.60    | 7688           | 1.16    | 10589 <sup>a</sup> |
| 90       | 0.00     | 0.00                        | 0.00     | 1.093            | 2.12    | 5806           | 1.34    | 9159               |
| 120      | 0.00     | 0.00                        | 0.00     | 1.093            | 2.69    | 4572           | 1.59    | 7713               |
| 167      | 0.00     | 0.00                        | 0.00     | 1.093            | 3.11    | 3957           | 2.22    | 5545               |
| 212      | 0.00     | 0.00                        | 0.00     | 1.093            | 3.58    | 3435           | 3.17    | 3877               |

<sup>a</sup>Design Condition

Conductor: Drake

795 kcmil-Type 16 ACSR/SD

Area = 0.7261 in.<sup>2</sup>Creep *is* a factor**Span = 1000 ft***NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 0        | 0.50     | 4.00                        | 0.30     | 2.486            | 20.65   | 15089             | 20.36   | 15299          |
| 32       | 0.50     | 0.00                        | 0.00     | 2.074            | 20.61   | 12607             | 19.32   | 13445          |
| −20      | 0.00     | 0.00                        | 0.00     | 1.093            | 12.20   | 11205             | 10.89   | 12552          |
| 0        | 0.00     | 0.00                        | 0.00     | 1.093            | 13.35   | 10244             | 11.56   | 11832          |
| 30       | 0.00     | 0.00                        | 0.00     | 1.093            | 15.22   | 8988              | 12.69   | 10779          |
| 60       | 0.00     | 0.00                        | 0.00     | 1.093            | 17.21   | 7950 <sup>a</sup> | 13.98   | 9780           |
| 90       | 0.00     | 0.00                        | 0.00     | 1.093            | 19.26   | 7108              | 15.44   | 8861           |
| 120      | 0.00     | 0.00                        | 0.00     | 1.093            | 21.31   | 6428              | 17.03   | 8037           |
| 167      | 0.00     | 0.00                        | 0.00     | 1.093            | 24.27   | 5647              | 19.69   | 6954           |
| 212      | 0.00     | 0.00                        | 0.00     | 1.093            | 25.62   | 5352              | 22.32   | 6136           |

<sup>a</sup>Design condition.

**Note: Calculations based on:** (1) NESC Heavy Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 0°F; b. Initial Unloaded – 25% RBS @ 60°F; Final Unloaded – 15% RBS @ 60°F.

conductor tension is increased until the sag in one or more suspension spans reaches the appropriate stringing sags based on the ruling span for the line section. The calculation of stringing sags is based on the preceding sag equation.

Table 14.13 shows a typical stringing sag table for a 600-ft ruling span of Drake ACSR with suspension spans ranging from 400 to 700 ft and conductor temperatures of 20–100°F. All values in this stringing table are calculated from ruling span initial tensions, shown in Table 14.12 using the parabolic sag equation.

## 14.5 Line Design Sag-Tension Parameters

In laying out a transmission line, the first step is to survey the route and draw up a plan-profile of the selected right-of-way. The plan-profile drawings serve an important function in linking together

**TABLE 14.13** Typical Sag and Tension Data 795 kcmil-37 Strand AAC “Arbutus,” 300- and 1000-ft Spans

| Conductor: Arbutus             |          |                          |          |               |         |                   |         |             |
|--------------------------------|----------|--------------------------|----------|---------------|---------|-------------------|---------|-------------|
| 795 kcmil-37 Strands AAC       |          |                          |          |               |         |                   |         |             |
| Area = 0.6245 in. <sup>2</sup> |          |                          |          |               |         |                   |         |             |
| Creep <i>is</i> a factor       |          |                          |          |               |         |                   |         |             |
| NESC Heavy Loading District    |          |                          |          |               |         |                   |         |             |
| Span = 300 ft                  |          |                          |          |               |         |                   |         |             |
| Temp, °F                       | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Weight, lb/ft | Final   |                   | Initial |             |
|                                |          |                          |          |               | Sag, ft | Tension, lb       | Sag, ft | Tension, lb |
| 30                             | 0.00     | 9.00                     | 0.05     | 1.122         | 3.56    | 3546              | 2.82    | 4479        |
| 30                             | 0.00     | 0.00                     | 0.00     | 0.746         | 2.91    | 2889              | 2.06    | 4075        |
| 60                             | 0.00     | 0.00                     | 0.00     | 0.746         | 4.03    | 2085 <sup>a</sup> | 2.80    | 2999        |
| 90                             | 0.00     | 0.00                     | 0.00     | 0.746         | 5.13    | 1638              | 3.79    | 2215        |
| 120                            | 0.00     | 0.00                     | 0.00     | 0.746         | 6.13    | 1372              | 4.86    | 1732        |
| 167                            | 0.00     | 0.00                     | 0.00     | 0.746         | 7.51    | 1122              | 6.38    | 1319        |
| 212                            | 0.00     | 0.00                     | 0.00     | 0.746         | 8.65    | 975               | 7.65    | 1101        |

<sup>a</sup>Design condition.

| Conductor: Arbutus             |          |                          |          |               |         |                   |         |             |
|--------------------------------|----------|--------------------------|----------|---------------|---------|-------------------|---------|-------------|
| 795 kcmil-37 Strands AAC       |          |                          |          |               |         |                   |         |             |
| Area = 0.6245 in. <sup>2</sup> |          |                          |          |               |         |                   |         |             |
| Creep <i>is</i> a factor       |          |                          |          |               |         |                   |         |             |
| NESC Heavy Loading District    |          |                          |          |               |         |                   |         |             |
| Span = 1000 ft                 |          |                          |          |               |         |                   |         |             |
| Temp, °F                       | Ice, in. | Wind, lb/ft <sup>2</sup> | K, lb/ft | Weight, lb/ft | Final   |                   | Initial |             |
|                                |          |                          |          |               | Sag, ft | Tension, lb       | Sag, ft | Tension, lb |
| 30                             | 0.00     | 9.00                     | 0.05     | 1.122         | 44.50   | 3185              | 42.85   | 3305        |
| 30                             | 0.00     | 0.00                     | 0.00     | 0.746         | 43.66   | 2158              | 41.71   | 2258        |
| 60                             | 0.00     | 0.00                     | 0.00     | 0.746         | 45.24   | 2085 <sup>a</sup> | 43.32   | 2175        |
| 90                             | 0.00     | 0.00                     | 0.00     | 0.746         | 46.76   | 2018              | 44.89   | 2101        |
| 120                            | 0.00     | 0.00                     | 0.00     | 0.746         | 48.24   | 1958              | 46.42   | 2033        |
| 167                            | 0.00     | 0.00                     | 0.00     | 0.746         | 50.49   | 1873              | 48.72   | 1939        |
| 212                            | 0.00     | 0.00                     | 0.00     | 0.746         | 52.55   | 1801              | 50.84   | 1860        |

<sup>a</sup>Design condition.

*Note: Calculations based on:* (1) NESC Light Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 30°F; b. Initial Unloaded – 25% RBS @ 60°F; c. Final Unloaded – 15% RBS @ 60°F.

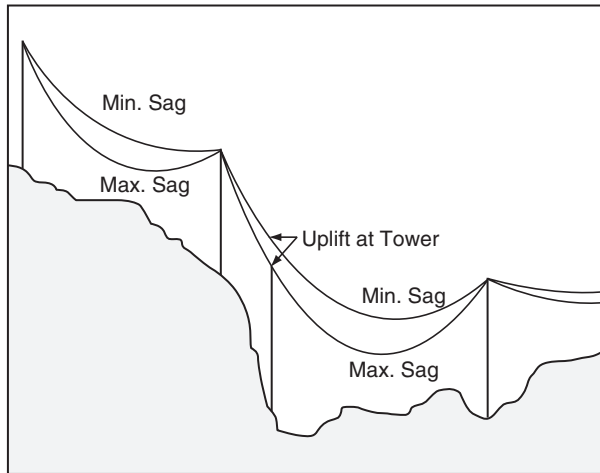
the various stages involved in the design and construction of the line. These drawings, prepared based on the route survey, show the location and elevation of all natural and man-made obstacles to be traversed by, or adjacent to, the proposed line. These plan-profiles are drawn to scale and provide the basis for tower spotting and line design work.

Once the plan-profile is completed, one or more estimated ruling spans for the line may be selected. Based on these estimated ruling spans and the maximum design tensions, sag-tension data may be calculated providing initial and final sag values. From this data, sag templates may be constructed to the same scale as the plan-profile for each ruling span, and used to graphically spot structures.

### 14.5.1 Catenary Constants

The sag in a ruling span is equal to the weight per unit length,  $w$ , times the span length,  $S$ , squared, divided by 8 times the horizontal component of the conductor tension,  $H$ . The ratio of conductor horizontal tension,  $H$ , to weight per unit length,  $w$ , is the catenary constant,  $H/w$ . For a ruling span sag-tension calculation using eight loading conditions, a total of 16 catenary constant values could be defined, one for initial and final tension under each loading condition.

Catenary constants can be defined for each loading condition of interest and are used in any attempt to locate structures. Some typical uses of catenary constants for locating structures are to avoid



**FIGURE 14.9** Conductor uplift.

overloading, assure ground clearance is sufficient at all points along the right-of-way, and minimize blowout or uplift under cold weather conditions. To do this, catenary constants are typically found for: (1) the maximum line temperature; (2) heavy ice and wind loading; (3) wind blowout; and (4) minimum conductor temperature. Under any of these loading conditions, the catenary constant allows sag calculation at any point within the span.

### 14.5.2 Wind Span

The maximum wind span of any structure is equal to the distance measured from center to center of the two adjacent spans supported by a structure. The wind span is used to determine the maximum horizontal force a structure must be designed to withstand under high wind conditions. Wind span is not dependent on conductor sag or tension, only on horizontal span length.

### 14.5.3 Weight Span

The weight span of a structure is a measure of the maximum vertical force a structure must be designed to withstand. The weight span is equal to the horizontal distance between the low points and the vertex of two adjacent spans. The maximum weight span for a structure is dependent on the loading condition being a minimum for heavy ice and wind load. When the elevations of adjacent structures are the same, the wind and weight spans are equal.

### 14.5.4 Uplift at Suspension Structures

Uplift occurs when the weight span of a structure is negative. On steeply inclined spans, the low point of sag may fall beyond the lower support. This indicates that the conductor in the uphill span is exerting a negative or upward force on the lower tower. The amount of this upward force is equal to the weight of the conductor from the lower tower to the low point in the sag. If the upward pull of the uphill span is greater than the downward load of the next adjacent span, actual uplift will be caused and the conductor will swing free of the tower. This usually occurs under minimum temperature conditions and must be dealt with by adding weights to the insulator suspension string or using a strain structure (Fig. 14.9).

### 14.5.5 Tower Spotting

Given sufficiently detailed plan-profile drawings, structure heights, wind/weight spans, catenary constants, and minimum ground clearances, structure locations can be chosen such that ground clearance is

maintained and structure loads are acceptable. This process can be done by hand using a sag template, plan-profile drawing, and structure heights, or numerically by one of several commercial programs.

## 14.6 Conductor Installation

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Installation of a bare overhead conductor can present complex problems. Careful planning and a thorough understanding of stringing procedures are needed to prevent damage to the conductor during the stringing operations. The selection of stringing sheaves, tensioning method, and measurement techniques are critical factors in obtaining the desired conductors sagging results. Conductor stringing and sagging equipment and techniques are discussed in detail in the *IEEE Guide to the Installation of Overhead Transmission Line Conductors*, IEEE Std. 524–1992. Some basic factors concerning installation are covered in this section. Because the terminology used for equipment and installation procedures for overhead conductors varies throughout the utility industry, a limited glossary of terms and equipment definitions excerpted from IEEE Std. 524–1992 is provided in the chapter appendix. A complete glossary is presented in the *IEEE Guide to the Installation of Overhead Transmission Line Conductors*.

### 14.6.1 Conductor Stringing Methods

There are two basic methods of stringing conductors, categorized as either slack or tension stringing. There are as many variations of these methods as there are organizations installing conductors. The selected method, however, depends primarily on the terrain and conductor surface damage requirements.

#### 14.6.1.1 Slack or Layout Stringing Method

Slack stringing of conductor is normally limited to lower voltage lines and smaller conductors. The conductor reel(s) is placed on reel stands or “jack stands” at the beginning of the stringing location. The conductor is unreeled from the shipping reel and dragged along the ground by means of a vehicle or pulling device. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor placed in stringing sheaves attached to the structure. The conductor is then reattached to the pulling equipment and the pull continued to the next structure.

This stringing method is typically used during construction of new lines in areas where the right-of-way is readily accessible to vehicles used to pull the conductor. However, slack stringing may be used for repair or maintenance of transmission lines where rugged terrain limits use of pulling and tensioning equipment. It is seldom used in urban areas or where there is any danger of contact with high-voltage conductors.

#### 14.6.1.2 Tension Stringing

A tension stringing method is normally employed when installing transmission conductors. Using this method, the conductor is unreeled under tension and is not allowed to contact the ground. In a typical tension stringing operation, travelers are attached to each structure. A pilot line is pulled through the travelers and is used, in turn, to pull in heavier pulling line. This pulling line is then used to pull the conductor from the reels and through the travelers. Tension is controlled on the conductor by the tension puller at the pulling end and the bullwheel tension retarder at the conductor payout end of the installation. Tension stringing is preferred for all transmission installations. This installation method keeps the conductor off the ground, minimizing the possibility of surface damage and limiting problems at roadway crossings. It also limits damage to the right-of-way by minimizing heavy vehicular traffic.

### 14.6.2 Tension Stringing Equipment and Setup

Stringing equipment typically includes bullwheel or drum pullers for back-tensioning the conductor during stringing and sagging; travelers (stringing blocks) attached to every phase conductor and shield wire attachment point on every structure; a bullwheel or crawler tractor for pulling the conductor through travelers; and various other special items of equipment. [Figure 14.10](#) illustrates a typical stringing and sagging setup for a stringing section and the range of stringing equipment required.

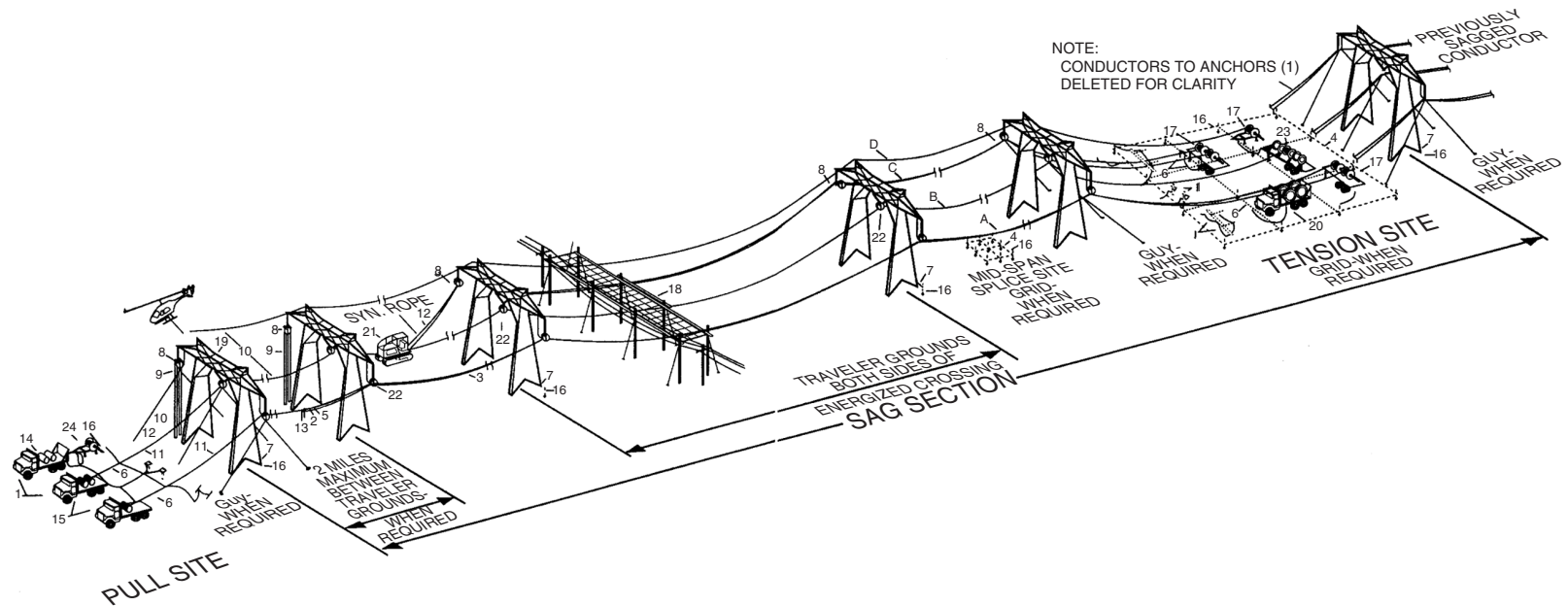


FIGURE 14.10 Tension stringing equipment setup.

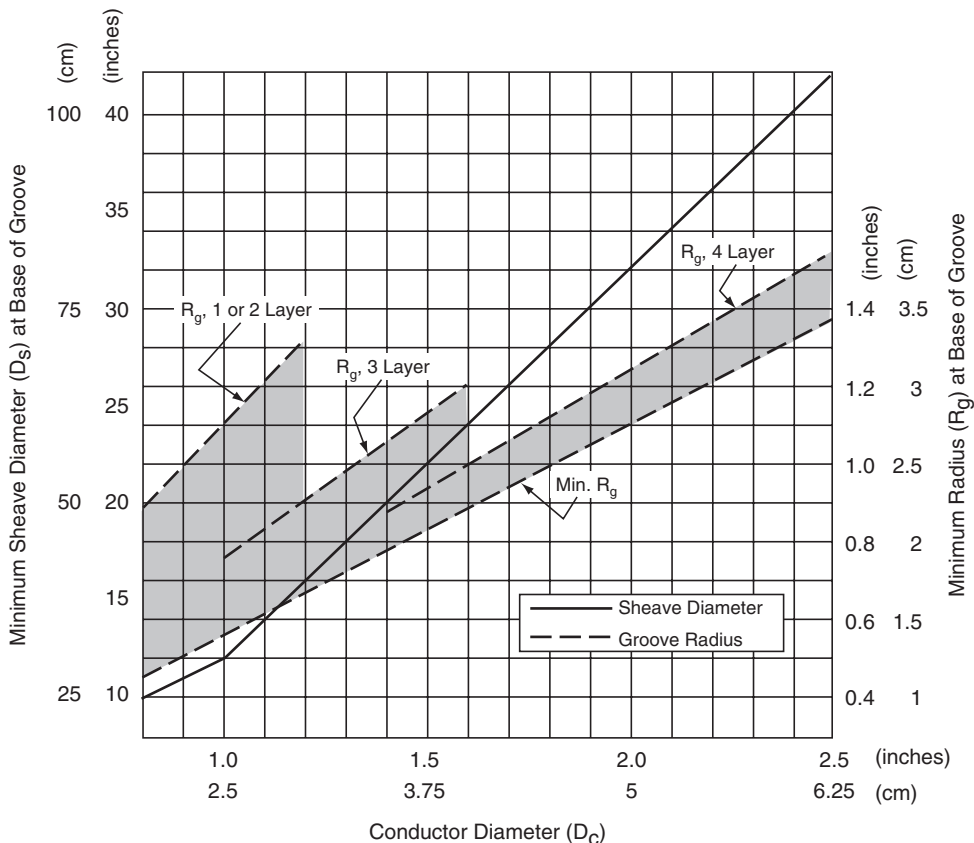


**FIGURE 14.11** Basket grip pulling device.

Provision for conductor splicing during stringing must be made at tension site or midspan sites to avoid pulling splices through the travelers.

During the stringing operation, it is necessary to use proper tools to grip the strands of the conductor evenly to avoid damaging the outer layer of wires. Two basic types or categories of grips are normally used in transmission construction. The first is a type of grip referred to as a pocketbook, suitcase, bolted, etc., that hinges to completely surround the conductor and incorporates a bail for attaching to the pulling line. The second type is similar to a Chinese finger grip and is often referred to as a basket or “Kellem” grip. Such a grip, shown in Fig. 14.11, is often used because of its flexibility and small size, making it easily pulled through sheaves during the stringing operation. Whatever type of gripping device is used, a swivel should be installed between the pulling grip and pulling line or running board to allow free rotation of both the conductor and the pulling line.

A traveler consists of a sheave or pulley wheel enclosed in a frame to allow it to be suspended from structures or insulator strings. The frame must have some type of latching mechanism to allow insertion and removal of the conductor during the stringing operation. Travelers are designed for a maximum safe working load. Always ensure that this safe working load will not be exceeded during the stringing operation. Sheaves are often lined with neoprene or urethane materials to prevent scratching of conductors in high-voltage applications; however, unlined sheaves are also available for special applications.



**FIGURE 14.12** Recommended minimum sheave dimensions.

Travelers used in tension stringing must be free rolling and capable of withstanding high running or static loads without damage. Proper maintenance is essential. Very high longitudinal tension loads can develop on transmission structures if a traveler should “freeze” during tension stringing, possibly causing conductor and/or structure damage. Significant levels of rotation resistance will also yield tension differences between spans, resulting in incorrect sag.

Proper selection of travelers is important to assure that travelers operate correctly during tension stringing and sagging. The sheave diameter and the groove radius must be matched to the conductor.

Figure 14.12 illustrates the minimum sheave diameter for typical stringing and sagging operations. Larger diameter sheaves may be required where particularly severe installation conditions exist.

### 14.6.3 Sagging Procedure

It is important that the conductors be properly sagged at the correct stringing tension for the design ruling span. A series of several spans, a line section, is usually sagged in one operation. To obtain the correct sags and to insure the suspension insulators hang vertically, the horizontal tension in all spans must be equal. Figures 14.13 through 14.18 depict typical parabolic methods and computations required

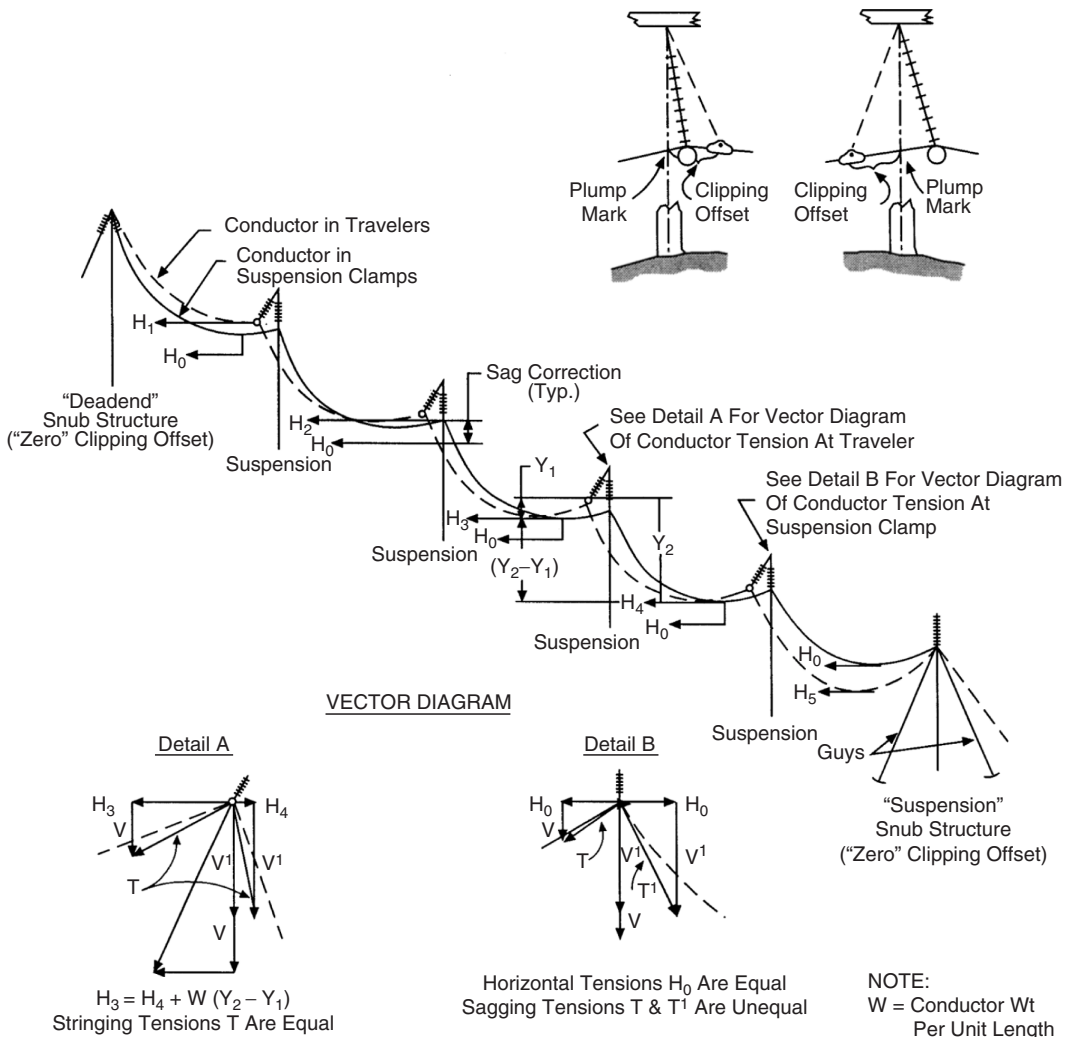
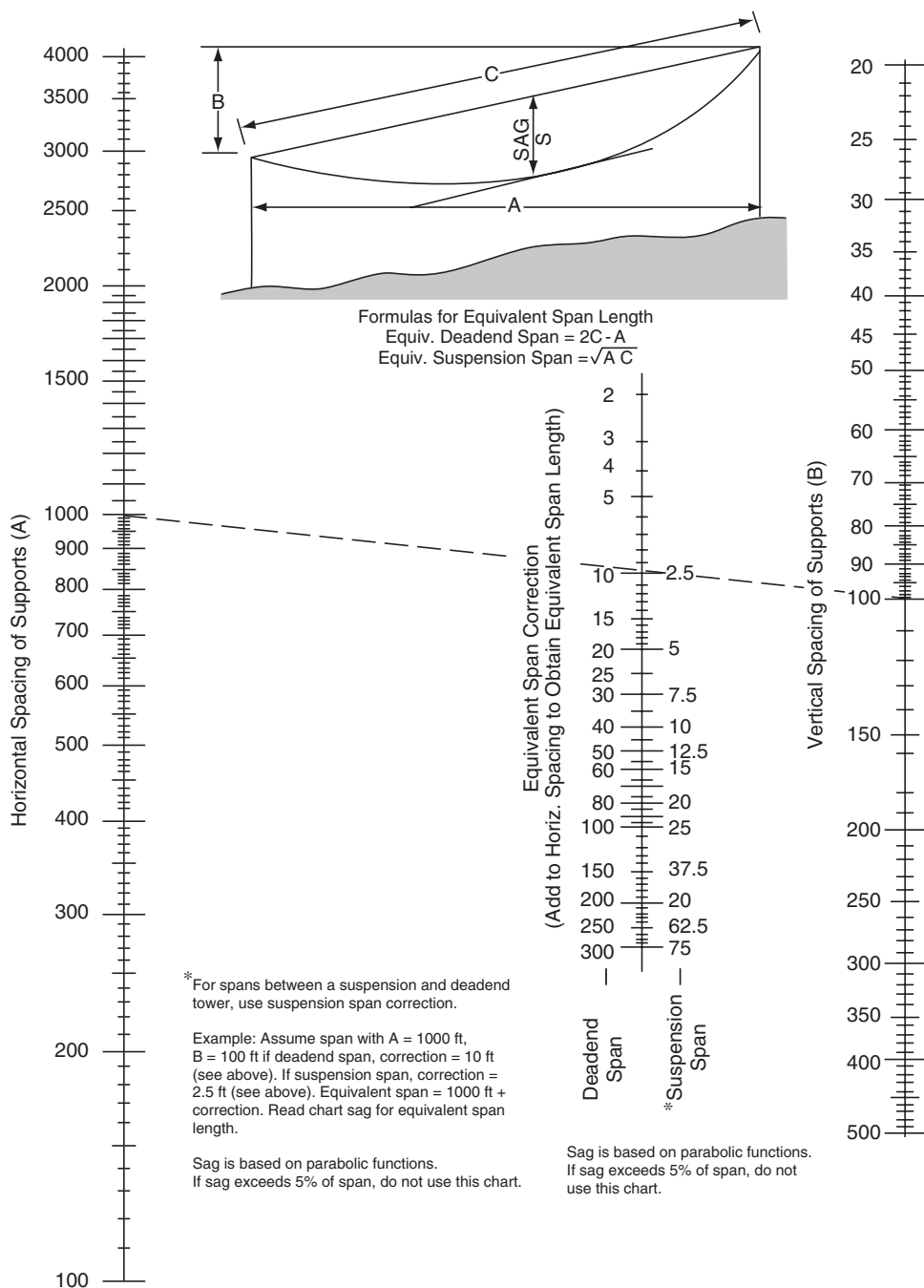


FIGURE 14.13 Clipping offset illustration.

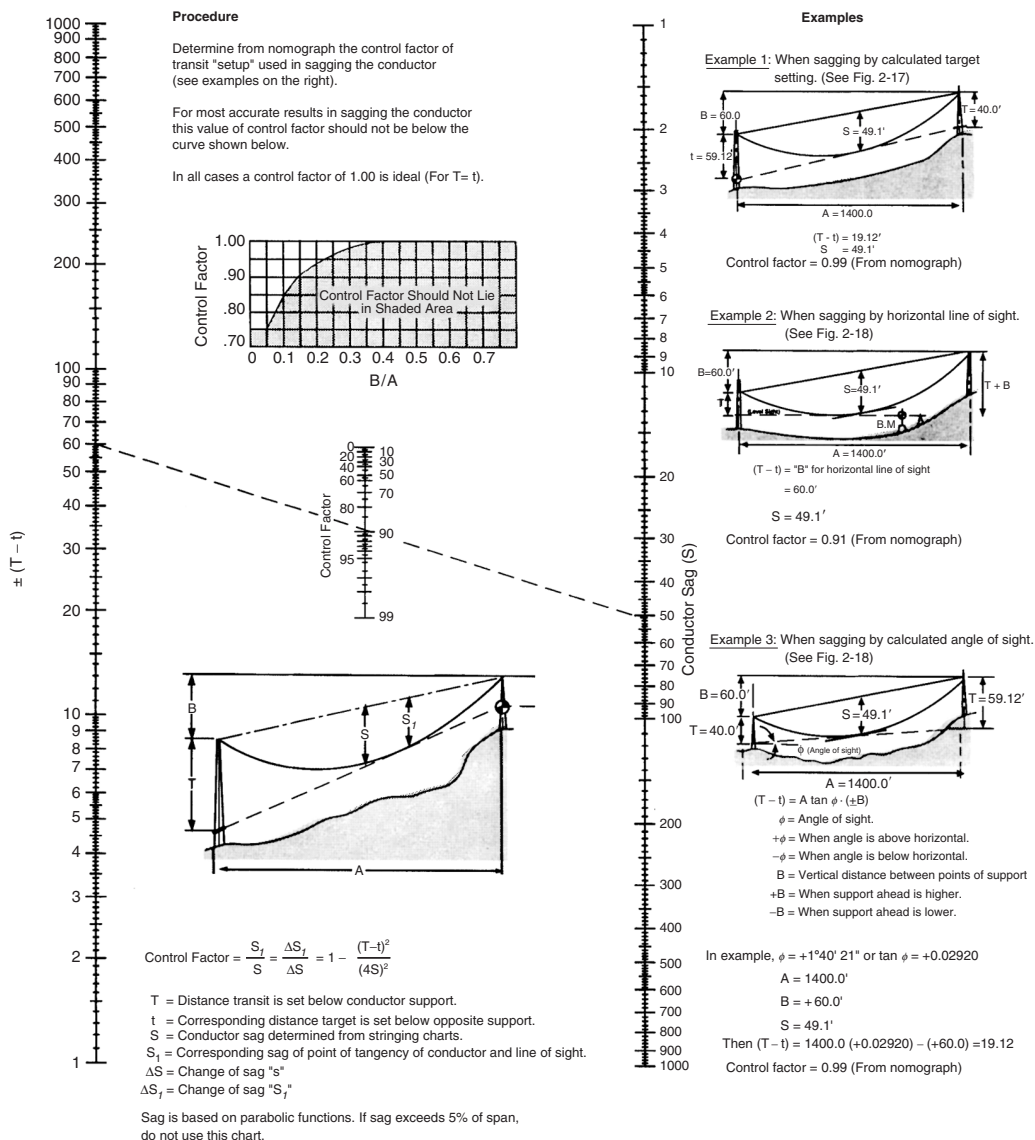




**FIGURE 14.14** Nomograph for determining level span equivalents of non-level spans.

for sagging conductors. Factors that must be considered when sagging conductors are creep elongation during stringing and prestressing of the conductor.

*Creep elongation during stringing:* Upon completion of conductor stringing, a time of up to several days may elapse before the conductor is tensioned to design sag. Since the conductor tension during the stringing process is normally well below the initial sagging tension, and because the conductor remains in the stringing sheaves for only a few days or less, any elongation due to creep is neglected. The

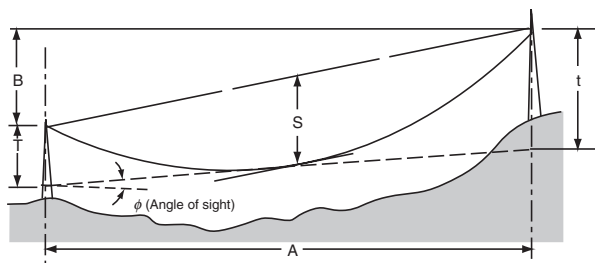


**FIGURE 14.15** Nomograph for determining control factor for conductor sagging.

conductor should be sagged to the initial stringing sags listed in the sag tables. However, if the conductor tension is excessively high during stringing, or the conductor is allowed to remain in the blocks for an extended period of time, then the creep elongation may become significant and the sagging tables should be corrected prior to sagging.

Creep is assumed exponential with time. Thus, conductor elongation during the first day under tension is equal to elongation over the next week. Using creep estimation formulas, the creep strain can be estimated and adjustments made to the stringing sag tables in terms of an equivalent temperature. Also, should this become a concern, Southwire's Wire and Cable Technology Group will be happy to work with you to solve the problem.

**Prestressing conductor:** Prestressing is sometimes used to stabilize the elongation of a conductor for some defined period of time. The prestressing tension is normally much higher than the unloaded design tension for a conductor. The degree of stabilization is dependent upon the time maintained at the



$$\text{METHOD 1: } \tan \phi = \frac{T \pm B - t}{A}$$

$$\text{METHOD 2: } \tan \phi = \frac{B + 2T - S(2+M)}{A}$$

$\phi$  = Angle of sight

+  $\phi$  When angle is above horizontal

–  $\phi$  When angle is below horizontal

t = Vertical distance below support to line of sight. (See Fig. 2-17).

T = Vertical distance below support for transit.

S = Sag

A = Horizontal distance between points of support - obtained from structure list or plan & profile

B = Vertical distance between points of support - obtained from plan & profile, tower site data sheets or field measurement.

+ B when support ahead is higher.

– B when support ahead is lower.

M = Determined from curve on Fig. 2-17.

#### EXAMPLES:

Given:

$$A = 1400.0'$$

$$B = +60.0'$$

$$T = 40.0'$$

$$S = 49.1' \quad @ \quad 60^\circ\text{F}$$

$$S = 51.2' \quad @ \quad 90^\circ\text{F}$$

$$T = 59.12' \quad @ \quad 60^\circ\text{F}$$

$$T = 63.76' \quad @ \quad 90^\circ\text{F}$$

#### METHOD 1

$$\tan \phi = \frac{T \pm B - t}{A}$$

$$\tan \phi_{60^\circ\text{F}} = \frac{40.0 - 60.0 - 59.12}{1400.0} = 0.02920$$

$$\phi_{60^\circ\text{F}} = +1^\circ 40' 21''$$

$$\tan \phi_{90^\circ\text{F}} = \frac{40.0 - 60.0 - 63.76}{1400.0} = 0.02589$$

$$\phi_{90^\circ\text{F}} = +1^\circ 28' 59''$$

$$\text{Change in angle } \phi \text{ for } 5^\circ\text{F} = (1^\circ 40' 21'' - 1^\circ 28' 59'') \left( \frac{5}{30} \right) = 0^\circ 1' 54''$$

#### METHOD 2

$$\tan \phi = \frac{B + 2T - S(2+M)}{A}$$

$$\tan \phi_{60^\circ\text{F}} = \frac{60.0 + (40.0)(2) - (49.1)(2+0.019)}{1400.0} = 0.02919$$

$$\phi_{60^\circ\text{F}} = +1^\circ 40' 19''$$

$$\tan \phi_{90^\circ\text{F}} = \frac{60.0 + (40.0)(2) - (51.2)(2+0.027)}{1400.0} = 0.02587$$

$$\phi_{90^\circ\text{F}} = +1^\circ 28' 55''$$

$$\text{Change in angle } \phi \text{ for } 5^\circ\text{F} = (1^\circ 40' 19'' - 1^\circ 28' 55'') \left( \frac{5}{30} \right) = 0^\circ 1' 54''$$

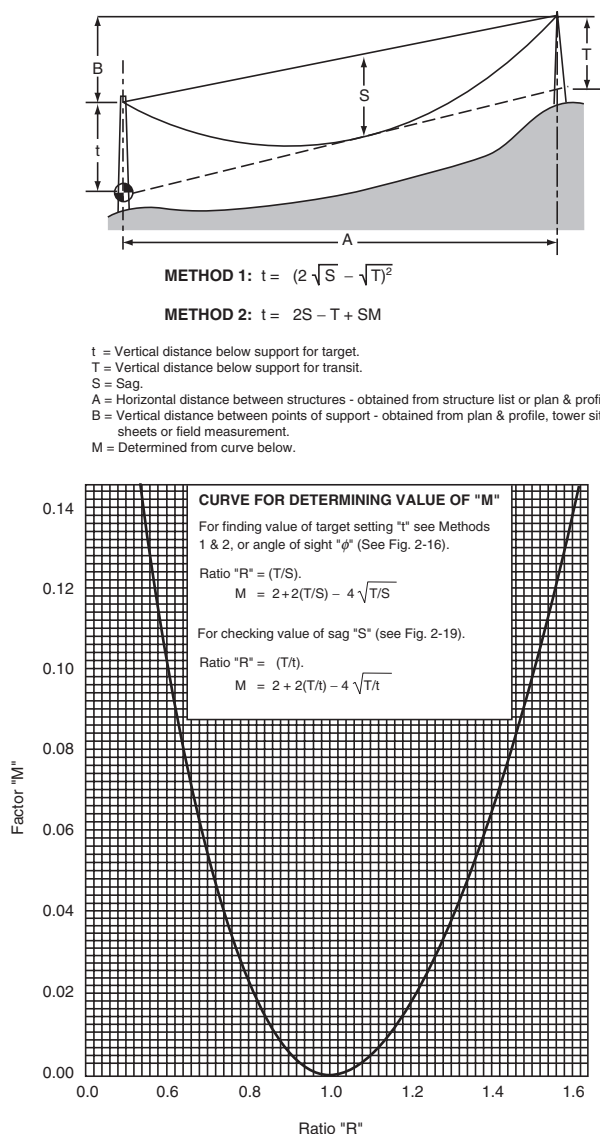
Sag is based on parabolic functions. If sag exceeds 5% of span, do not use this chart.

**FIGURE 14.16** Conductor sagging by calculated angle of sight.

prestress tension. After prestressing, the tension on the conductor is reduced to stringing or design tension limits. At this reduced tension, the creep or plastic elongation of the conductor has been slowed, reducing the permanent elongation due to strain and creep for a defined period of time. By tensioning a conductor to levels approaching 50% of its breaking strength for times on the order of a day, creep elongation will be temporarily halted (Cahill, 1973). This simplifies concerns about creep during subsequent installation but presents both equipment and safety problems.

#### 14.6.3.1 Sagging by Stopwatch Method

A mechanical pulse imparted to a tensioned conductor moves at a speed proportional to the square root of tension divided by weight per unit length. By initiating a pulse on a tensioned conductor and measuring the time required for the pulse to move to the nearest termination, the tension, and thus



**FIGURE 14.17** Conductor sagging by calculated target method.

the sag of the conductor, can be determined. This stopwatch method (Overend and Smith) has come into wide use even for long spans and large conductors.

The conductor is struck a sharp blow near one support and the stopwatch is started simultaneously. A mechanical wave moves from the point where the conductor was struck to the next support point at which it will be partially reflected. If the initiating blow is sharp, the wave will travel up and down the span many times before dying out. Time-sag tables such as the one shown in Table 14.14 are available from many sources. Specially designed sagging stopwatches are also available.

The reflected wave can be detected by lightly touching the conductor but the procedure is more likely to be accurate if the wave is both initiated and detected with a light rope over the conductor. Normally, the time for the return of the 3rd or 5th wave is monitored.

Traditionally, a transit sagging method has been considered to be more accurate for sagging than the stopwatch method. However, many transmission-line constructors use the stopwatch method exclusively, even with large conductors.

## EXAMPLES

Given:

A = 1400.0'  
B = 60.0'  
T = 40.0'  
S = 49.1' @ 60°F  
S = 51.2' @ 90°F

## METHOD 1

$$t = (2\sqrt{S} - \sqrt{T})^2$$

$$\sqrt{T} = 6.325$$

$$\sqrt{S_{60^\circ\text{F}}} = 7.007$$

$$2\sqrt{S_{60^\circ\text{F}}} = 14.014$$

$$t_{60^\circ\text{F}} = 59.12'$$

$$\sqrt{S_{90^\circ\text{F}}} = 7.155$$

$$2\sqrt{S_{90^\circ\text{F}}} = 14.310$$

$$t_{90^\circ\text{F}} = 63.76'$$

$$\text{Change in "t" for } 5^\circ\text{F} = (63.76 - 59.12) \left( \frac{5}{30} \right) = 0.77'$$

## METHOD 2

$$t = 2S - T + SM$$

$$T/S_{60^\circ\text{F}} = 0.815$$

$$M_{60^\circ\text{F}} = 0.019$$

$$2S_{60^\circ\text{F}} = 98.2'$$

$$t_{60^\circ\text{F}} = 59.13'$$

$$T/S_{90^\circ\text{F}} = 0.781$$

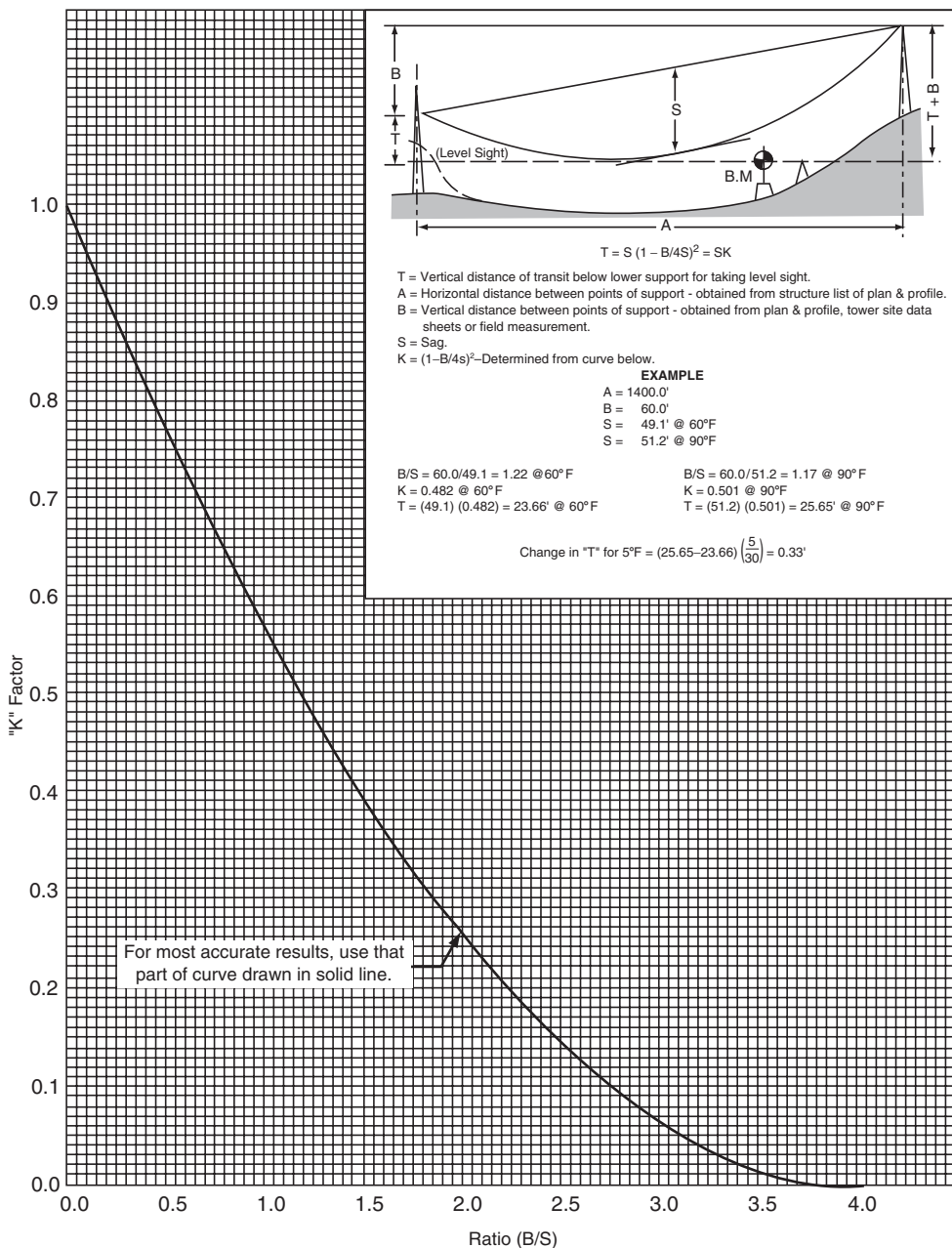
$$M_{90^\circ\text{F}} = 0.027$$

$$2S_{90^\circ\text{F}} = 102.4'$$

$$t_{90^\circ\text{F}} = 63.78'$$

$$\text{Change in "t" for } 5^\circ\text{F} = (63.76 - 59.13) \left( \frac{5}{30} \right) = 0.78'$$

Sag is based on parabolic functions.  
If sag exceeds 5% of span, do not use this chart.



Sag is based on parabolic functions. If sag exceeds 5% of span, do not use this chart.

**FIGURE 14.18** Conductor sagging by horizontal line of sight.

### 14.6.3.2 Sagging by Transit Methods

IEEE Guide Std. 524–1993 lists three methods of sagging conductor with a transit: “Calculated Angle of Sight,” “Calculated Target Method,” and “Horizontal Line of Sight.” The method best suited to a particular line sagging situation may vary with terrain and line design.

**TABLE 14.14** Typical Sag and Tension Data 795 kcmil-37 Strand AAC “Arbutus,” 300- and 1000-ft Spans

Conductor: Arbutus

795 kcmil-37 Strands AAC

Area = 0.6245 in.<sup>2</sup>Creep *is* a factor**Span = 300 ft**

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 0        | 0.50     | 4.00                        | 0.30     | 2.125            | 3.97    | 6033              | 3.75    | 6383           |
| 32       | 0.50     | 0.00                        | 0.00     | 1.696            | 4.35    | 4386              | 3.78    | 5053           |
| –20      | 0.00     | 0.00                        | 0.00     | 0.746            | 1.58    | 5319              | 1.39    | 6055           |
| 0        | 0.00     | 0.00                        | 0.00     | 0.746            | 2.00    | 4208              | 1.59    | 5268           |
| 30       | 0.00     | 0.00                        | 0.00     | 0.746            | 2.91    | 2889              | 2.06    | 4075           |
| 60       | 0.00     | 0.00                        | 0.00     | 0.746            | 4.03    | 2085 <sup>a</sup> | 2.80    | 2999           |
| 90       | 0.00     | 0.00                        | 0.00     | 0.746            | 5.13    | 1638              | 3.79    | 2215           |
| 120      | 0.00     | 0.00                        | 0.00     | 0.746            | 6.13    | 1372              | 4.86    | 1732           |
| 167      | 0.00     | 0.00                        | 0.00     | 0.746            | 7.51    | 1122              | 6.38    | 1319           |
| 212      | 0.00     | 0.00                        | 0.00     | 0.746            | 8.65    | 975               | 7.65    | 1101           |

<sup>a</sup>Design condition.

Conductor: Arbutus

795 kcmil-37 Strands AAC

Area = 0.6245 in.<sup>2</sup>Creep *is* a factor**Span = 1000 ft***NESC Heavy Loading District*

| Temp, °F | Ice, in. | Wind,<br>lb/ft <sup>2</sup> | K, lb/ft | Weight,<br>lb/ft | Final   |                   | Initial |                |
|----------|----------|-----------------------------|----------|------------------|---------|-------------------|---------|----------------|
|          |          |                             |          |                  | Sag, ft | Tension,<br>lb    | Sag, ft | Tension,<br>lb |
| 0        | 0.50     | 4.00                        | 0.30     | 2.125            | 45.11   | 59.53             | 44.50   | 6033           |
| 32       | 0.50     | 0.00                        | 0.00     | 1.696            | 45.80   | 4679              | 44.68   | 4794           |
| –20      | 0.00     | 0.00                        | 0.00     | 0.746            | 40.93   | 2300              | 38.89   | 2418           |
| 0        | 0.00     | 0.00                        | 0.00     | 0.746            | 42.04   | 2240              | 40.03   | 2350           |
| 30       | 0.00     | 0.00                        | 0.00     | 0.746            | 43.66   | 2158              | 41.71   | 2258           |
| 60       | 0.00     | 0.00                        | 0.00     | 0.746            | 45.24   | 2085 <sup>a</sup> | 43.32   | 2175           |
| 90       | 0.00     | 0.00                        | 0.00     | 0.746            | 46.76   | 2018              | 44.89   | 2101           |
| 120      | 0.00     | 0.00                        | 0.00     | 0.746            | 48.24   | 1958              | 46.42   | 2033           |
| 167      | 0.00     | 0.00                        | 0.00     | 0.746            | 50.49   | 1873              | 48.72   | 1939           |
| 212      | 0.00     | 0.00                        | 0.00     | 0.746            | 52.55   | 1801              | 50.84   | 1860           |

<sup>a</sup>Design condition.

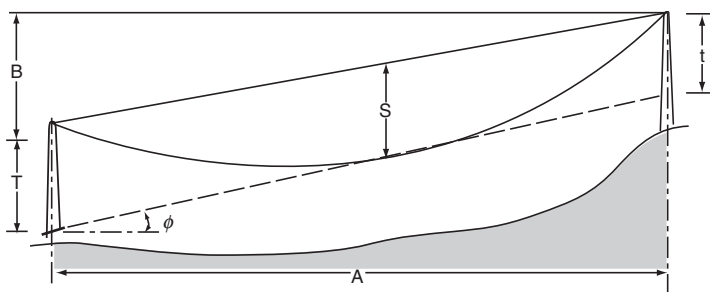
**Note: Calculations based on:** (1) NESC Light Loading District. (2) Tension Limits: a. Initial Loaded – 60% RBS @ 0°F; b. Initial Unloaded – 25% RBS @ 60°F; c. Final Unloaded – 15% RBS @ 60°F.

### 14.6.3.3 Sagging Accuracy

Sagging a conductor during construction of a new line or in the reconductoring of a old line involves many variables that can lead to a small degree of error. IEEE Std. 524–1993 suggests that all sags be within 6 in. of the stringing sag values. However, aside from measurement errors during sagging, errors in terrain measurement and variations in conductor properties, loading conditions, and hardware installation have led some utilities to allow up to 3 ft of margin in addition to the required minimum ground clearance.

### 14.6.3.4 Clipping Offsets

If the conductor is to be sagged in a series of suspension spans where the span lengths are reasonably close and where the terrain is reasonably level, then the conductor is sagged using conventional stringing sag tables and the conductor is simply clipped into suspension clamps that replace the travelers. If the



$$\text{METHOD 1: } S = \left( \frac{\sqrt{T} + \sqrt{t}}{2} \right)^2$$

$$\text{METHOD 2: } S = \frac{B}{2} + \frac{t}{2} - \frac{tM}{8}$$

- S = Sag  
 t = Vertical distance below support to line of sight.  
 =  $T \pm B - A \tan \phi$  when angle  $\phi$  is above horizontal.  
 =  $T \pm B + A \tan \phi$  when angle  $\phi$  is below horizontal.  
 T = Vertical distance below support for transit.  
 B = Vertical distance between points of support - obtained from plan & profile,  
 tower site data sheets or field measurement.  
 + B when support ahead is higher.  
 - B when support ahead is lower.  
 A = Horizontal distance between points of support - obtained from structure list  
 or plan & profile  
 $\phi$  = Angle of sight  
 M = Determined from curve on Fig. 2.17.

## EXAMPLES

Given:

$$\begin{aligned}
 A &= 1400.0' \\
 B &= 60.0' \\
 T &= 40.0' \\
 \phi &= +1^\circ 40' 21'' @ 60^\circ\text{F} \\
 &\quad (\text{Field Measured})
 \end{aligned}$$

### METHOD 1

$$S = \left( \frac{\sqrt{T} + \sqrt{t}}{2} \right)^2$$

$$t = 40.0 + 60.0 - 1400.0 \tan 1^\circ 40' 21''$$

$$= 59.12'$$

$$\sqrt{t} = 7.689$$

$$\sqrt{T} = 6.325$$

$$S_{60^\circ\text{F}} = 49.1'$$

### METHOD 2

Note: When using Method 2, value, "T" should lie between 3/4 "S" & 4/3 "S"

$$S = \frac{B}{2} + \frac{t}{2} - \frac{tM}{8}$$

$$t = 59.12'$$

$$t/2 = 29.56'$$

$$T/2 = 20.0''$$

$$M = 0.061$$

$$S_{60^\circ\text{F}} = 20.0 + 29.56 - \frac{(59.12)(0.061)}{8}$$

$$S_{60^\circ\text{F}} = 49.1'$$

Sag is based on parabolic functions. if sag exceeds 5% of span, do not use this chart.

FIGURE 14.19 Conductor sagging for checking sag S.

conductor is to be sagged in a series of suspension spans where span lengths vary widely or more commonly, where the terrain is steep, then clipping offsets may need to be employed in order to yield vertical suspension strings after installation.

Clipping offsets are illustrated in Fig. 14.19, showing a series of steeply inclined spans terminated in a "snub" structure at the bottom and a "deadend" structure at the top. The vector diagram illustrates a balance of total conductor tension in the travelers but an imbalance in the horizontal component of tension.

## 14.7 Defining Terms

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**Block**—A device designed with one or more single sheaves, a wood or metal shell, and an attachment hook or shackle. When rope is reeved through two of these devices, the assembly is commonly referred to as a *block and tackle*. A *set of 4s* refers to a block and tackle arrangement utilizing two 4-inch double-sheave blocks to obtain four load-bearing lines. Similarly, a *set of 5s* or a *set of 6s* refers to the same number of load bearing lines obtained using two 5-inch or two 6-inch double-sheave blocks, respectively.

*Synonyms:* set of 4s, set of 5s, set of 6s.

**Bullwheel**—A wheel incorporated as an integral part of a bullwheel puller or tensioner to generate pulling or braking tension on conductors or pulling lines, or both, through friction. A puller or tensioner normally has one or more pairs arranged in tandem incorporated in its design. The physical size of the wheels will vary for different designs, but 17-in. (43 cm) face widths and diameters of 5 ft (150 cm) are common. The wheels are power driven or retarded and lined with single- or multiple-groove neoprene or urethane linings. Friction is accomplished by reeving the pulling line or conductor around the groove of each pair.

**Clipping-in**—The transferring of sagged conductors from the traveler to their permanent suspension positions and the installing of the permanent suspension clamps.

*Synonyms:* clamping, clipping.

**Clipping offset**—A calculated distance, measured along the conductor from the plum mark to a point on the conductor at which the center of the suspension clamp is to be placed. When stringing in rough terrain, clipping offset may be required to balance the horizontal forces on each suspension structure.

**Grip, conductor**—A device designed to permit the pulling of conductor without splicing on fittings, eyes, etc. It permits the pulling of a *continuous* conductor where threading is not possible. The designs of these grips vary considerably. Grips such as the Klein (Chicago) and Crescent utilize an open-sided rigid body with opposing jaws and swing latch. In addition to pulling conductors, this type is commonly used to tension guys and, in some cases, pull wire rope. The design of the come-along (pocketbook, suitcase, four bolt, etc.) incorporates a bail attached to the body of a clamp which folds to completely surround and envelope the conductor. Bolts are then used to close the clamp and obtain a grip.

*Synonyms:* buffalo, Chicago grip, come-along, Crescent, four bolt, grip, Klein, pocketbook, seven bolt, six bolt, slip-grip, suitcase.

**Line, pilot**—A lightweight line, normally synthetic fiber rope, used to pull heavier pulling lines which in turn are used to pull the conductor. Pilot lines may be installed with the aid of finger lines or by helicopter when the insulators and travelers are hung.

*Synonyms:* lead line, leader, P-line, straw line.

**Line, pulling**—A high-strength line, normally synthetic fiber rope or wire rope, used to pull the conductor. However, on reconstruction jobs where a conductor is being replaced, the old conductor often serves as the pulling line for the new conductor. In such cases, the old conductor must be closely examined for any damage prior to the pulling operations.

*Synonyms:* bull line, hard line, light line, sock line.

**Puller, bullwheel**—A device designed to pull pulling lines and conductors during stringing operations.

It normally incorporates one or more pairs of urethane- or neoprene-lined, power-driven, single- or multiple-groove bullwheels where each pair is arranged in tandem. Pulling is accomplished by friction generated against the pulling line which is reeved around the grooves of a pair of the bullwheels. The puller is usually equipped with its own engine which drives the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner.

*Synonym:* puller.

**Puller, drum**—A device designed to pull a conductor during stringing operations. It is normally equipped with its own engine which drives the drum mechanically, hydraulically, or through a combination of both. It may be equipped with synthetic fiber rope or wire rope to be used as the



pulling line. The pulling line is payed out from the unit, pulled through the travelers in the sag section and attached to the conductor. The conductor is then pulled in by winding the pulling line back onto the drum. This unit is sometimes used with synthetic fiber rope acting as a pilot line to pull heavier pulling lines across canyons, rivers, etc.

*Synonyms:* hoist, single drum hoist, single drum winch, tugger.

**Puller, reel**—A device designed to pull a conductor during stringing operations. It is normally equipped with its own engine which drives the supporting shaft for the reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, drives the reel. The application of this unit is essentially the same as that for the drum puller previously described. Some of these devices function as either a puller or tensioner.

**Reel stand**—A device designed to support one or more reels and having the possibility of being skid, trailer, or truck mounted. These devices may accommodate rope or conductor reels of varying sizes and are usually equipped with reel brakes to prevent the reels from turning when pulling is stopped. They are used for either slack or tension stringing. The designation of reel trailer or reel truck implies that the trailer or truck has been equipped with a reel stand (jacks) and may serve as a reel transport or *payout* unit, or both, for stringing operations. Depending upon the sizes of the reels to be carried, the transporting vehicles may range from single-axle trailers to semi-trucks with trailers having multiple axles.

*Synonyms:* reel trailer, reel transporter, reel truck.

**Running board**—A pulling device designed to permit stringing more than one conductor simultaneously with a single pulling line. For distribution stringing, it is usually made of lightweight tubing with the forward end curved gently upward to provide smooth transition over pole cross-arm rollers. For transmission stringing, the device is either made of sections hinged transversely to the direction of pull or of a hard-nose rigid design, both having a flexible pendulum tail suspended from the rear. This configuration stops the conductors from twisting together and permits smooth transition over the sheaves of bundle travelers.

*Synonyms:* alligator, bird, birdie, monkey tail, sled.

**Sag section**—The section of line between snub structures. More than one sag section may be required in order to properly sag the actual length of conductor which has been strung.

*Synonyms:* pull, setting, stringing section.

**Site, pull**—The location on the line where the puller, reel winder, and anchors (snubs) are located. This site may also serve as the pull or tension site for the next sag section.

*Synonyms:* reel setup, tugger setup.

**Site, tension**—The location on the line where the tensioner, reel stands and anchors (snubs) are located. This site may also serve as the pull or tension site for the next sag section.

*Synonyms:* conductor payout station, payout site, reel setup.

**Snub structure**—A structure located at one end of a sag section and considered as a *zero* point for sagging and clipping offset calculations. The section of line between two such structures is the sag section, but more than one sag section may be required in order to sag properly the actual length of conductor which has been strung.

*Synonyms:* 0 structure, zero structure.

**Tensioner, bullwheel**—A device designed to hold tension against a pulling line or conductor during the stringing phase. Normally, it consists of one or more pairs of urethane- or neoprene-lined, power braked, single- or multiple-groove bullwheels where each pair is arranged in tandem. Tension is accomplished by friction generated against the conductor which is reeved around the grooves of a pair of the bullwheels. Some tensioners are equipped with their own engines which retard the bullwheels mechanically, hydraulically, or through a combination of both. Some of these devices function as either a puller or tensioner. Other tensioners are only equipped with friction-type retardation.

*Synonyms:* retarder, tensioner.

**Tensioner, reel**—A device designed to generate tension against a pulling line or conductor during the stringing phase. Some are equipped with their own engines which retard the supporting shaft for

the reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, retards the reel. Some of these devices function as either a puller or tensioner. Other tensioners are only equipped with friction type retardation.

*Synonyms:* retarder, tensioner.

**Traveler**—A sheave complete with suspension arm or frame used separately or in groups and suspended from structures to permit the stringing of conductors. These devices are sometimes bundled with a center drum or sheave, and another traveler, and used to string more than one conductor simultaneously. For protection of conductors that should not be nicked or scratched, the sheaves are often lined with nonconductive or semiconductive neoprene or with nonconductive urethane. Any one of these materials acts as a padding or cushion for the conductor as it passes over the sheave. Traveler grounds must be used with lined travelers in order to establish an electrical ground.

*Synonyms:* block, dolly, sheave, stringing block, stringing sheave, stringing traveler.

**Winder reel**—A device designed to serve as a recovery unit for a pulling line. It is normally equipped with its own engine which drives a supporting shaft for a reel mechanically, hydraulically, or through a combination of both. The shaft, in turn, drives the reel. It is normally used to rewind a pulling line as it leaves the bullwheel puller during stringing operations. This unit is not intended to serve as a puller, but sometimes serves this function where only low tensions are involved.

*Synonyms:* take-up reel.

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